ELEMENTS OF HYDROGRAPHIC SURVEYING

BY

GEORGE WOOD LOGAN

Commander, U. S. Navy

ANNAPOLIS, MD.

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PREFACE.

The object in view in the preparation of this work has been to furnish a text-book for the instruction of midshipmen at the U. S. Naval Academy; as a consequence, the subject has been treated with particular reference to the requirements of the course at that institution. The limitation thus placed has prevented the detailed description of certain features occasionally involved in surveying operations of the most precise nature, as, for example, astronomical transit observations; but all branches of the work connected with a marine hydrographic survey as ordinarily carried out have been completely described, and the book is therefore available for purposes of reference for naval officers and others that may be engaged in such work.

In the preparation of the book, existing works on the subject were freely consulted, especially Phelps' *Practical Marine Surveying,* Wharton's *Hydrographical Surveying,* Bowditch's *American Practical Navigator* (revised edition), and Gurley's *Manual of Surveying Instruments;* and much valuable assistance was received from Mr. G. W. Littlehales, Hydrographic Engineer, of the Hydrographic Office of the U. S. Navy Department. Acknowledgment is also made of the courtesy of Messrs. W. and L. E. Gurley, of Troy, N. Y., who supplied the illustrations of the various instruments.

Certain methods described for measuring a broken base and for delineating shore-line, together with some practical hints on minor points, are the result of the author's own experience, and are not known to have been previously published.

G. W. L.

WASHINGTON, D. C., March, 1907.

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ELEMENTS OF HYDROGRAPHIC SURVEYING.

CHAPTER I.

OUTLINE OF A HYDROGRAPHIC SURVEY.

1. Object.—A marine hydrographic survey has for its object the delineation, for purposes of navigation, of a given area of the earth's surface. It should show, at frequent intervals, the depth of water and character of bottom, especially near shoals and dangers, the visible objects upon the surface of the water, and the natural forms and artificial features of adjacent masses of land. The whole should be represented in accordance with a determined system of projection and, excepting for limited areas, referred to a series of parallels and meridians from which the geographical position of any point may be derived.

2. General Procedure.—Before describing in detail the instruments and methods whereby this is accomplished, it will be well to outline the procedure involved, and to summarize the various steps with a view to an understanding of the part that each contributes to the whole.

3. The foundation of all work is the *base line,* which is, ordinarily, the only line directly measured. Its extremities are chosen with a view to obtaining the greatest length capable of measurement by linear methods, and the line thus determined should afford a favorable base for extension by methods of triangulation. The extremities of the base line are marked by *signals* of such character as to facilitate recognition of those points from other locations within the field of the survey; and signals are similarly constructed upon a number of

points, called *triangulation points* or *stations,* so chosen as to outline the whole area and to afford positions of reference for the details of topography and hydrography within the regions that respectively adjoin them.

4. The triangulation points thus selected are, in surveys of moderate extent, of two classes—*main* or *primary,* and *secondary.* The former afford the basis for the series of principal triangles and quadrilaterals which build up the network from the base to the most distant points of the field; they should be so chosen as to give a series of well-conditioned figures throughout, but should be no closer together than necessary for fulfilling this object. The secondary points are placed between those of the main system, being located from the latter and from each other, and furnish the means of establishing details of depth, shore-line, etc.; hence it follows that they must be sufficiently close together to permit of several being in view within every locality to be developed.

5. Having measured the base, constructed the main and secondary signals, and measured the necessary angles for establishing the positions of the triangulation points, the work proceeds with the observation of the *topography,* which includes all features on land that require delineation—such as shore-line, elevations, and the prominent objects, natural or artificial, that may be recognized by the navigator; and of the *hydrography,* or characteristics of the water area, which includes such features as depth of water, character of bottom, and the position of lightships, buoys, and dangers.

6. *Astronomical observations* are made for the determination of the geographical co-ordinates of some definite point, and of the true azimuth of some definite line, of the survey; these observations give the means of plotting, in their true relation to the earth's meridians and parallels, the measured base and all points derived from it by methods of triangulation.

7. *Magnetic observations* are made with the object of determining the variation of the compass at one or more points included in the survey, together with the magnetic dip and intensity.

8. *Tidal observations* include the collection of data concerning tides and tidal currents which are furnished the navigator on charts and in sailing directions; the record of tidal heights is also essential for the reduction to the plane of reference adopted for the chart of every sounding made during the survey.

9. In careful surveys, a *check base line* is measured between two main triangulation points remote from the origin, as a means of verification of work that has gone before. A *check azimuth* and, in very extensive surveys, a *check observation of geographical co-ordinates* serve a similar purpose.

10. *Sailing directions* are compiled from observations made during the survey, and the notes necessary for this purpose are made as the work proceeds.

11. **The first step** upon arriving on the survey ground is to make a *reconnaissance* of the whole area within which work is to be performed, with a view to a systematic laying-out of the plan of operations. The position of the base line, being a matter of great importance, should not be decided upon until after every available location has been inspected and its advantages and disadvantages weighed; the location of triangulation stations is of next importance, and should be taken up in connection with the selection of a base. Each of the other details should also be considered, and, as far as practicable, the whole plan should be prepared before actual work begins. A little time sacrificed in careful arrangement of preliminaries is well repaid by the smoothness and rapidity with which later work will flow.

12. **The order** in which the various parts of the survey proper are taken up is largely a matter of convenience and is

subject to wide variation in practice. The steps have just been enumerated in the order which is perhaps the most natural one, and this is very frequently followed. The signals must be constructed and their relative positions located on a preliminary sheet by triangulation before the hydrography and topography are taken up; and *tidal observations must be in progress when sounding begins;* but with these exceptions the surveyor is not bound to any fixed program. The base line is usually measured at an early period of the work, though this is not essential, as the triangulation may be plotted on an assumed scale of which the true value need not be known until the base measurement is completed. Astronomical and magnetic observations may be made at any time, but are usually among the later things taken up, unless the party includes an observer available for exclusive assignment to this class of work.

13. There is a chance for the display of judgment, on the part of the person directing the survey, in making the best of opportunity and keeping everybody employed. For example, when the work is of such extent that it is taken up in successive sections, signal-building and triangulation can be in progress in one section while the hydrography and topography are being completed in the preceding one; then when the parties engaged at the latter work move up to the next section they find signals awaiting and preliminary sheets made. Similarly, a period of fair weather will be devoted to offshore boat work and that part of the survey disposed of while conditions are favorable; otherwise the whole party may be held up in idleness, when everything else is done, by the prevalence of a rough sea which, while preventing outside work, would not have interfered with harbor work.

It may be remarked, in this connection, that while surveying involves the hardest sort of manual work, both for officers and men, it is usually undertaken with cheerfulness and welcomed as a change from the routine of ship duties and discipline. To

foster this attitude, a commanding officer will find it profitable, during a survey, to suspend temporarily as many as possible of the regulations relating to uniform, smoking in boats, etc., and to relax the rigidity as to brass and paint-work; it is surprising to find how, with a few such concessions, a day's work at heaving the lead or carrying scantlings up a mountain-side will be regarded as a genuine holiday.

CHAPTER II.

INSTRUMENTS FOR HYDROGRAPHIC SURVEYING.

14. The instruments chiefly used for observations and plotting in connection with a hydrographic survey are the theodolite or transit, plane table, telemeter or stadia, surveyor's compass, Y-level, sextant, heliotrope or heliograph, three-arm protractor, beam compass, proportional dividers, and the usual drawing instruments.

THE THEODOLITE AND TRANSIT.

15. The theodolite is designed for the precise measurement of horizontal and vertical angles and the observation of magnetic bearings.

16. The transit is the name given to that form of theodolite in which the telescope is sufficiently short to permit of its being *transited* (*i. e.,* revolved 180° about a horizontal axis) without removal from the supports; in modern practice this includes all but the largest theodolites.

17. Description.—While varying in mechanical details according to manufacture, the essential principles are common to all instruments of this class. A telescope (fig. 1) is so mounted as to have motion about two axes exactly at right angles to one another, which, when the instrument is adjusted, are respectively horizontal and vertical; cross-wires are placed in this telescope at the common focus of the eye-piece and object-lens. By means of a graduated circle and vernier, an observer may measure the angular motion of the axis of the telescope in a horizontal plane, and in some instruments similar provision is made for measurements in a vertical plane.

FIG. 1.

The instrument is ordinarily mounted upon a tripod; at its base, together with the leveling device, are the sockets and spindle which provide for revolution in a horizontal plane. Above these are two parallel plates moving one upon the other and capable of being brought to the true horizontal by the action of the leveling-screws as indicated by a pair of spirit-levels placed at right angles to one another on the upper plate. The lower of the two plates comprises a limb having angular graduations, and this plate has a clamp and tangent-screw by means of which it may either be freed from the vertical axis of the instrument, or clamped thereto, or given slow motion upon that axis. The upper plate carries one or more verniers graduated for reading the limb of the plate below; it is immovably attached to the spindle which constitutes the vertical axis of the instrument, and by means of a clamp and tangent-screw may be either freed from the lower plate, or clamped thereto, or given slow motion about the vertical axis relatively to that plate. Affixed to the upper plate are the supports for the telescope, which provide for the latter, when in adjustment, a truly horizontal axis of revolution. In connection with these supports are a clamp and tangent-screw for controlling the elevation of the telescope; a vernier for reading angles of elevation is also attached to the supports in those instruments where the telescope is provided with a graduated vertical arc or circle. Telescopes frequently carry levels to indicate the true zero for vertical angles.

On the upper plate is carried a magnetic needle mounted in a case with graduated periphery, the latter being sometimes made capable of motion about its own center to provide for the compass error; a reading vernier may be provided. The direction of the north-and-south line of the graduation is made to coincide with the axis of the telescope, always revolving with the telescope; the positions of East and West on the card are interchanged, by which arrangement, as will be seen

from figure 2, the needle always indicates the compass direction in which the telescope is pointing. The difference between this method and that of the mariner's compass will be apparent when it is considered that in the latter the card is affixed to the needle with its north point always toward the north, while in the surveyor's compass the card is turned until its north point lies in the direction to be observed.

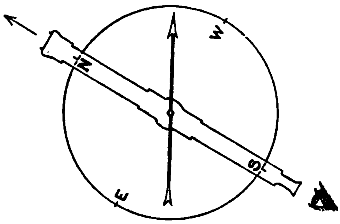


FIG. 2.

A theodolite is always provided with a plumb-bob which may be suspended from a point exactly beneath its true center (the intersection of horizontal and vertical axes) to permit of the instrument being placed directly over a given point.

18. Surveyor's Transit.—Transits vary in detail according to the particular class of work for which they are designed, and are distinguished as *surveyors' transits, engineers' transits,* or *mountain transits.* Of these, the first-named is probably most frequently employed in hydrographic work; in its usual form, this instrument has a compass needle about 5 inches long, the circle for which is made movable for setting off variation; the vertical circle is complete, having a diameter of $4\frac{1}{2}$ inches, its vernier reading to 1 minute; the telescope carries a level; there are two verniers for reading horizontal angles.

19. The line, or **axis, of collimation** of any telescope is one drawn from the optical center of the object-lens in a direction at right angles to its axis of rotation.

20. The line of sight is one drawn from the optical center of the object-lens to the point of intersection of the cross wires.

21. The adjustment of a theodolite or transit requires that certain conditions be fulfilled as enumerated below. All instruments should be in perfect adjustment on leaving the hands of a maker, and many remain so adjusted for an indefinite time; it is important, however, for a surveyor to verify the correctness of an instrument newly received and to satisfy himself from time to time that no derangement occurs during use. Assuming that the instrument is free from radical faults that would be revealed by an expert inspection prior to purchase, as would be the case with one furnished to a naval surveying vessel, the following may be stated as the requisite adjustments, together with their importance and the methods of determination and correction.

(*a*) *The bubbles of plate-levels must be in central position when the plates are horizontal.* (Requires frequent verification.) Set up the instrument upon its tripod in an approximately level position, pressing the tripod legs down to a firm foundation; unclamp the upper or lower plate, or both, and swing the instrument so as to bring the two levels respectively parallel to the lines joining the diagonally opposite leveling-screws; by manipulating one pair of screws bring the bubble of the corresponding level to its central position, and proceed similarly with the other pair and its level, afterward rectifying the first level if it has been thrown out by the adjustment of the second. Both bubbles being central, swing the telescope through 180° in azimuth; the bubbles should retain their same positions if the adjustment is perfect; if they do not, the small adjusting-nut at the end of each level should be turned, by means of the pin provided for the purpose, until one-half the error is corrected; then the instrument should again be leveled with the screws and the operation repeated until both bubbles remain central throughout a complete azimuthal revo-

lution of the telescope. To illustrate the reason for this, let HO (fig. 3) be the inclination of the level when, in the first position, it is brought to the horizontal; let PP' be the plate, inclined to the level at the angle POH; suppose, now, that the plate and level are revolved through 180° about the axis, OX, of the instrument, the latter being perpendicular to PP'; the inclination of the plate to HH', the horizontal, evidently re-

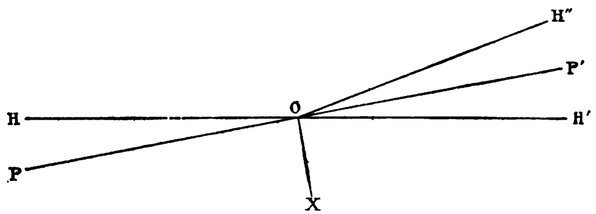


FIG. 3.

mains the same; but the level, which is at an angle $H''OP'$ ($= HOP$) above the plate, is now at an angle $H''OH'$ ($= 2HOP$) above the horizontal; hence, by reducing the latter angle one-half by means of the adjusting-nut the level is made parallel to the plate; and thereafter the plate may be brought to the horizontal by the leveling-screws, following the indications of the bubble.

(*b*) *The common focus of eye-piece and objective should be at the cross-wires.* (Requires verification each time the telescope is focused.) Direct the telescope toward the object to be observed and move the eye-piece out or in until the cross-wires appear to be in the best possible focus; then move the object-lens until the distant object is likewise most distinct, bringing the vertical wire upon some definite part of it. Move the eye sidewise and note whether or not the wire appears to move relatively to the object; if it does, the eye-piece must be moved slightly—in, if the apparent motion of the wire is in

the same direction as the eye, or out, if in the opposite direction; then readjust the focus of the objective and repeat the test until there is no apparent motion.

(*c*) *The vertical cross-wire must be perpendicular to the horizontal axis of the telescope.* (Needs occasional verification.) Direct the telescope toward a sharply defined point and bring the latter on with the upper part of the vertical wire; then elevate the telescope and observe whether the lower part of the wire continues to bisect the same point. If it does not, the diaphragm in which the cross-wires are carried should be turned circumferentially until the adjustment is made. Diaphragms are always fitted to allow of this as well as of lateral and vertical movement.

(*d*) *The axis of collimation and line of sight must be identical.* (Requires frequent verification.) In figure 4, assume that O is the center of the instrument; OA, the axis of colli-

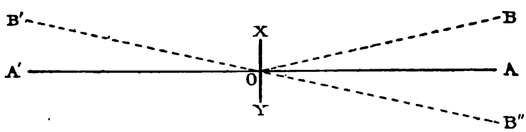


FIG. 4.

mation; and OB, the line of sight, differing from OA by the amount of collimation error, BOA. Consider that the telescope is clamped with one vernier on zero of the scale and the vertical wire bisecting B, a clearly defined object two to three hundred feet distant. Transit the telescope, and it will rotate upon its horizontal axis, XY, at right angles to OA, bringing the axis of collimation into the position OA' on a prolongation of OA, and the line of sight to OB', the collimation error being $B'OA' = BOA$. By the graduated scale revolve the telescope upon its vertical axis through 180° of azimuth; the line of sight is now OB'', the line of collimation

returning to OA, and the angle, $B''OB$, between the object now on the cross-wire and the object first sighted is twice the collimation error. To correct it, unclamp the upper plate and, again bisecting B with the cross-wire, read the limb; divide the angle thus obtained by 2 and set the vernier at a position on the scale corresponding with this half-angle, whence the line of sight bisects $B''OB$ and the line of collimation becomes OB; if, therefore, the line of sight be shifted to the direction OB by moving the diaphragm laterally until B comes on the vertical wire, the adjustment will be made.

For verification of the correctness of the adjustment thus made, a modification of the method may be adopted. Bisect with the vertical wire a visible mark to northward (say) of the instrument; transit and observe the point which will then be bisected to southward, placing a mark thereon, if necessary; rotate the telescope in azimuth until the first mark is again bisected; and, finally, transit again, when the telescope will be directed to a point removed from the second or southern mark by an angle corresponding to four times the collimation error, as may be readily proved by a diagram. Any small residual error thus revealed may be corrected by setting the cross-wire upon a point one-fourth the distance from the mark, as determined either by linear or angular methods.

In adjusting the cross-wire diaphragm for this and similar corrections, it must be remembered that the image of those wires is inverted by the eye-piece, and that they must therefore be moved in a direction opposite to the apparent one as viewed through the eye-piece. In every case, after making a correction involving motion of the cross-wire diaphragm, care should be taken to go back and verify any adjustments of the wires that have gone before.

(*e*) *The horizontal axis of the telescope must be perpendicular to the vertical one.* (Requires only occasional verification; in some instruments, this adjustment is considered

permanent and no provision is made for correction.) The adjustments previously described having been made, direct the telescope toward the top of some well-defined object at a considerable elevation, as a point on a spire, pole, or building; then depress the telescope until the vertical wire bisects a mark at or below the horizontal. Now transit the telescope, and turn in azimuth about the vertical axis until the upper mark is again bisected; then depress, and observe whether the lower mark is still on the cross-wire. If it is not, one-half the error should be corrected by raising or lowering the adjustable support for the horizontal axis—the right-hand support being raised if the object appears to the right of the wire, or lowered if to the left; or the reverse for the left-hand support. Repeat the test until the adjustment is correct.

(*f*) *The zeros of the vertical circle and vernier must be coincident, and the bubble at center of telescope level, when line of collimation is horizontal.* (Essential only when measuring vertical angles, but then requiring frequent verification.) The instrument having been carefully leveled by the plate-levels and the zero of the vernier being on with the zero of the vertical scale, bisect a mark, selected or set up at a moderate distance, with the horizontal cross-wire of the telescope. Transit the telescope, then revolve in azimuth about the vertical axis, and again bisect the mark with the horizontal wire. If the zeros are in coincidence the vernier is correctly placed; if not, the reading of the scale should be noted, and the telescope set to a position midway between this and the zero reading; then, by moving the diaphragm vertically, bring the wire on the object again. Finally, loose the vernier on the telescope support and move it until the zeros once more become coincident. What has thus been done is to correct half the error by the wire and half by the vernier, and if, on second trial, the accuracy of the adjustment is verified, the axis of collimation will be horizontal when the vernier is at zero; and

while in this position the bubble of the telescope should be worked to its central position by the adjusting nuts, in which position it should remain during a complete azimuthal swing of the telescope. This is an equivalent case to adjustment *d,* the sole difference being that one deals with the horizontal, and the other with the vertical plane of the instrument; the detailed explanation given for adjustment *d,* with its diagram (fig. 4), may therefore be made applicable for this adjustment.

22. If the telescope is too long to permit of being transited in the usual way, it may be lifted from its Y's and turned through 180° upon its longitudinal axis, which will be equivalent to transiting about the horizontal axis and revolving back through 180° on the vertical axis, as required for corrections *d, e,* and *f.*

23. To use the theodolite or transit, the adjustment being complete, it should be carefully set up at the station from which observations are to be made. This involves, first, placing the instrument on its tripod in a nearly level position above the center mark and bringing the plumb-bob directly over that mark—an operation facilitated by the *shifting head,* a device that permits small motions of the instrument upon the head of the tripod without lifting the latter; second, leveling the instrument by the plate-levels; and third, focusing the telescope as already described.

24. To occupy a station is the term given to the operation of making the required measurement of angles at that station.

25. To measure a horizontal angle, unclamp the upper plate and swing it until the attached vernier (or that vernier to be adopted as standard) approaches the zero of the graduated limb of the lower plate; then clamp it, and, by means of the tangent-screw, observing the graduations with the reading glass, bring the two zeros into exact coincidence. Next, the lower plate being unclamped, swing the telescope until the vertical wire bisects one of the objects, *the final motion being*

given, as in every case, by clamping the plate and using the tangent-screw; in this condition, both plates are clamped, the telescope is exactly sighted upon one object, and the vernier reads zero. Now unclamp the upper plate and swing the telescope until the second object is brought nearly upon the vertical cross-wire; clamp the upper plate and with the upper tangent-screw bring the object exactly on the cross-wire, and the required angle may be read off the scale.

26. Instruments vary in the method of graduation of the horizontal limb, but most frequently two sets of graduations will be found—one from 0° to 360° increasing to the right, and one increasing from 0° to 90° and again decreasing to 0° in each semi-circle. It should be made an invariable practice to measure all angles toward the right—that is, to swing the telescope from the left-hand toward the right-hand object; this avoids the necessity of writing "right" or "left" after each angle to indicate the method of measurement, eliminates the confusion that may arise from different directions of reading of the vernier, and cultivates a uniformity of procedure that is conducive to accuracy.

27. An instrument of the finer class is usually provided with two verniers on the horizontal limb, 180° apart, distinguished by the marks "A" and "B." For precise work it is well to read both and take the mean of their readings above 0° and 180°, respectively, as the true reading; but the precision of construction of modern instruments is such as to render discrepancies in reading exceptional, and the principal advantage of the double vernier is that one is always conveniently near to the eye, whichever way the telescope tube may be directed.

28. A round of angles is taken by clamping the telescope at zero, as previously described, upon a given object, and then swinging it successively to each other object to be observed about the horizon (unclamping only the upper plate for purposes of swinging); the reading should be noted at each ob-

ject, and the telescope should finally be directed at the first point sighted upon; if this last reading is zero it proves that the lower plate has not moved during the operation. A round of angles gives data for obtaining the angular distance between any two observed objects at a given station.

29. To repeat an angle, make the first measurement as described for measuring a single horizontal angle; then, by loosening the lower plate, direct the telescope again at the first object, leaving the upper plate clamped to the lower at the reading corresponding to the first measure; clamp the lower plate; now unclamp the upper plate and swing the telescope once more to the second object, bisect it and clamp the upper plate, when, as will be evident, the scale reading will equal twice the angle; repeat this process as often as the importance of the angle may render expedient; the accumulated total divided by the number of repetitions gives the final value; in case more than a complete circle is passed over, the accumulated total consists of the number of such circles multiplied by 360° *plus* the final scale reading. The method of repeating is advantageous not only because it gives the benefit of presumably increased accuracy due to an increased number of observations, but also because it may afford a "fineness of reading" of a given angle beyond the limits of graduation of the instrument. Thus, suppose an angle of 10° 00′ 20″ were to be measured on a transit having a limb reading to half-minutes; the nearest possible reading for a single observation would be 10° 00′ 30″, or 10″ in error; if this angle were repeated eight times the true angle of 80° 02′ 40″ would be read as 80° 02′ 30″, one-eighth of which, or 10° 00′ 19″, would be only 1″ from the truth.

30. In recording repeated angles it is essential to put down only the first measure, the total reading, and the number of repetitions; a record of the reading of the single angle is important since, if it approximately equals the final mean, it

shows that there has been no gross error; but time will be saved by omitting the readings at the intermediate repetitions, as these are of practically no use.

31. In a series of repeated angles one-half the number should be taken with *telescope direct* and one-half with *telescope reversed.* A certain number being measured in the usual way, the telescope is transited and a like number of observations are made with the telescope in this inverted position. The object of this is to make errors due to faulty adjustment offset one another. Upon reversing the telescope there is no need to set the vernier back to zero and begin a new series, as the position of the upper plate with relation to the lower is not changed by the transit of the telescope, and in making the total number of readings accumulative the fineness of reading is increased.

32. To measure a vertical angle, the process corresponds with the measurement of a horizontal one, the horizontal wire being brought to bisect the objects instead of the vertical, and the vertical limb and vernier taking the place of the horizontal. The method of observing angles with the telescope both direct and reversed is similarly applicable, and is quite as essential for elimination of vertical as of horizontal errors of adjustment.

THE PLANE TABLE.

33. The Plane Table (fig. 5) consists essentially of a drawing-board or table so mounted as to be capable of being set in a truly horizontal position over a station of the survey; upon this board is placed a chart, or sheet of paper designed to represent, upon a certain scale, the area to be surveyed, and upon which are set down, in their appropriate places, the positions of two or more established stations of the survey. If, now, such a table be set up horizontally with a point *a* of the chart directly over the corresponding terrestrial station, *A*, of the

survey, and if it be so turned that the direction from *a* of a second point, *b*, on the chart coincides with that of the corresponding terrestrial station, *B*, then all azimuths of the chart laid down from the station occupied will be coincident with

FIG. 5.

corresponding azimuths of the earth, and a line drawn on the chart from *a* toward any visible station, *C*, will include the point *c* which represents that station on the chart. To facilitate the drawing of such lines, the plane table is provided with an *alidade*, consisting either of a telescope with cross-wires or

of a pair of sight-vanes, so mounted in connection with a rule or straight-edge that the line of sight is always in the same vertical plane as the edge of the rule.

34. The principle of the plane table is illustrated in diagram by figure 6. Let the rectangle represent a plane table carrying the chart under construction, set up in a horizontal position with its point *a* vertically above the station *A*, the

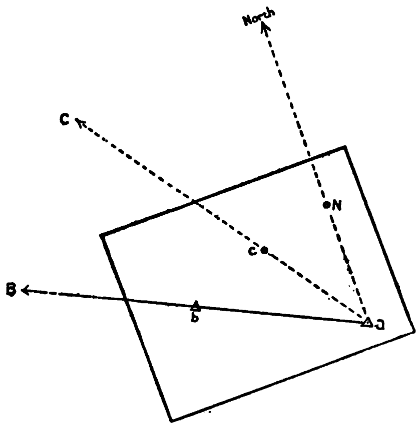


FIG. 6.

latter in coincidence with *a* on this projection; and let the board be turned in azimuth until the line joining *a* and *b* on the chart (or, more strictly, the vertical plane through those points) shall pass through *B*, a determined station of the survey with which *b* corresponds. Then it follows that every line drawn upon the chart from *a* will coincide with a similar line from *A* upon the earth's surface; and thus, if the alidade be placed with the edge of its ruler on that true meridian of the chart which passes through *a*, the line of sight will be true north; or if, while the straight-edge is on *a*, the line of sight

be directed toward any station, *C,* then the line drawn along the ruler will include the corresponding point, *c,* of the chart.

35. To orient the plane table is the term given to the process of placing it at a given station in such manner that each line of the chart shall lie in the same vertical plane as the corresponding line upon the earth's surface.

36. Like all instruments, plane tables vary in mechanical details with different manufacturers and with the different classes of work for which they are intended; but the general features are common to all. The surface of the drawing-board is made a perfect plane, and by the use of several pieces of wood placed with varying directions of grain, every care is taken to prevent warping; by means of rollers and clips at the edges, the paper is kept flat upon the board while readily capable of adjustment in position. Through fittings upon its lower side the board is attached to the head of the tripod upon which it is carried, this head, on account of the greater necessity for stability, being made larger than in tripods employed for other instruments. The devices employed in attaching, leveling, and orienting the table differ widely; in the more accurate varieties of instrument they include two horizontal plates, moving one upon the other, with leveling-screws and tangent-screw similar in principle to those employed for the theodolite.

To provide for plumbing any definite point of the sheet over the center mark of a station, a C-shaped *plumbing arm* is sometimes provided, as shown in the figure; in this attachment the hook on the lower arm, from which hangs the bob, is vertically beneath the pointer on the upper arm, which is placed on the required point of the sheet; the necessary plumbing in most cases, however, may be done with sufficient accuracy by the eye.

The *alidade* is a metal straight-edge having, in the accurate forms of the instrument, a telescope with cross-wires mounted upon a metal standard at its center; the telescope is carried in

supports, and has attached to it a vertical arc or circle, with tangent-screw and vernier, adapted to measuring vertical angles. In a simpler instrument provided for rough work the telescope is replaced by two vertical sight-vanes mounted at the extremities of the straight-edge.

An accessory called the *declinator* is supplied with the plane table, consisting of a magnetic needle mounted in a rectangular case of which the edges are respectively parallel and perpendicular to the north and south line of the compass graduation. The declinator may be placed upon the table at any point; by laying the edge of the case upon the magnetic meridian of the sheet the table may be oriented; or, having been oriented by sighting upon a determined terrestrial object, the declinator affords a ready means for drawing the meridian upon the sheet.

The true level of the table is indicated to the observer by a pair of spirit-levels at right angles to one another placed either on the declinator or on the straight edge of the alidade; in some instruments a single bubble is substituted.

37. The adjustment of a plane table embodies practically the same principles as the adjustment of a theodolite, the plane table being, indeed, a theodolite in which the results of observation of angles is graphically laid down in the field instead of being recorded by numerical measure for future plotting. Assuming the fiducial edge of the rule truly straight and the instrument free from like radical faults, the surveyor must verify the following:

(*a*) *The bubbles of levels must be in their central position when the table is horizontal.* Set up the plane table with the tripod legs firmly shoved down and in such position that the table is nearly horizontal and at a convenient height for observation. Place upon the table either the declinator or the alidade, whichever may carry the levels, in such position that the levels register the respective directions of motion of the

leveling-screws. Bring both bubbles to their middle position by the screws, then shift their position through 180° by turning the declinator or alidade; if the bubbles retain the same position they are in proper adjustment; if not, correct half the error by the adjusting-nuts, level the instrument again by the screws, and verify as before.

(*b*) *The common focus of eye-piece and objective should be at the cross-wires.*

(*c*) *The vertical wire must be perpendicular to the horizontal axis of the telescope.*

(*d*) *The axis of collimation and line of sight must be identical.*

(*e*) *The horizontal axis of the telescope must be perpendicular to the vertical one.*

(*f*) *The zeros of the vertical circle and vernier must be coincident, and the bubble at center of telescope level, when the line of collimation is horizontal.* (Essential only when measuring vertical angles.)

These adjustments are made in the manner that has hitherto (art. 21) been described for a theodolite or transit. Slight modifications must, however, be adopted according to the method in which the telescope is fitted for adjustment of the collimation error.

If the telescope can be revolved upon its horizontal axis like a transit instrument, the adjustments are made as with that instrument, except that since there is no graduated limb for azimuthal measure, the axis of collimation is revolved through an exact 180° about a vertical axis by first drawing a line along the straight-edge, and then revolving the alidade until the straight-edge is placed in coincidence with that line upon its opposite side.

In cases where the telescope can not be transited, the usual method is to have it carried in a cylindrical sleeve so fitted that it may be revolved through exactly 180° about the line of

collimation as an axis; in this case, the process is the same as described for a theodolite that must be shifted in its supports (art. 22).

38. The use of the plane table covers three cases:

(*a*) A station of determined position being occupied, to draw from it toward an undetermined station a direction-line for the location of the latter—called the method of *prosection;*

(*b*) A station of undetermined position being occupied with the table oriented, to draw toward it from a determined station a direction-line for the location of the former—called the method of *resection;*

(*c*) A station of undetermined position being occupied, to locate it by observation of three determined stations—called the *three-point* method.

As a preliminary to use for any purpose, the plane table is set up and leveled and the telescope focused, as described for purposes of adjustment. The table is then approximately oriented by means of the declinator, placing the north-and-south edge of the latter upon the magnetic meridian of the sheet and swinging the table until the compass needle points due north.

39. Prosection.—To illustrate the method of prosection, let it be assumed that a determined station of the survey, *A,* is occupied, and that the plotted position of that station upon the sheet, *a,* (fig. 7) is directly over its center mark; let *B* be another determined station, plotted upon the sheet at *b.* Perfect the orientation of the table by placing the alidade on the line *ab* * and bringing the telescope to bisect *B.* Now if *C* be a recognizable object whose position it is intended to establish, swing the alidade, always keeping its edge upon *a,* until the vertical wire bisects *C;* then draw the line *ac.* It is now

* The order in which stations are named indicates the direction of sight; thus, *ab* means that the telescope is directed from *a* to *b.*

known that the point c lies upon the line drawn, but its exact position is not yet established; it may, however, be determined either by the intersection of a second direction-line similarly obtained from another station (preferably by at least two other such lines intersecting the first at the same point), or

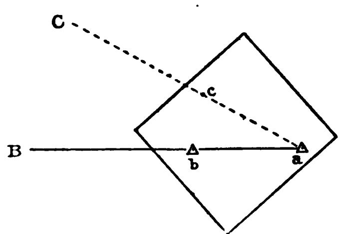


FIG. 7.

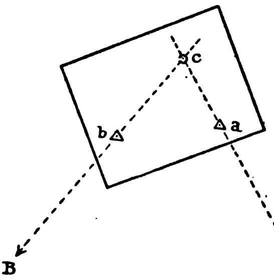


FIG. 8.

by laying off upon ac, on appropriate scale, the distance from A to C as obtained by stadia (art. 43) or other measurement.

40. Resection.—To locate a point by resection, assume that the station c (fig. 8) is occupied, and that we know nothing regarding its position except that the line ac represents its direction from A. Place the telescope upon the line ca and swing the table until A is brought upon the cross-wire, when it will be properly oriented; then, keeping the edge of the rule upon b, bisect the station B and draw the line cb; the intersection of this line with ca gives the required point c, the accuracy of which should be verified by resecting upon other established stations.

41. Three-point method.—Should it be required to determine the position of an occupied station to which no prosection line has been drawn from any other station, and as to which there is therefore no data upon the sheet, an approximate method which will serve most purposes consists in ori-

enting the table as accurately as possible by the magnetic needle and drawing three lines by resection, which, if the orientation has been correct, will intersect in a point; if these lines do not cut perfectly, but form a small triangle instead, the table should be swung slightly and other trials made until the conditions are fulfilled.

A second method of locating the point occupied is by an application of the three-point problem (art. 142); clamp the table and lay upon its surface a piece of tracing-paper (or linen), affixing it temporarily so that its position will not be disturbed as the alidade is moved upon it. Assume any point upon the tracing-paper as the position of the station, and, keeping the straight-edge upon this point, direct the telescope and draw lines successively to three stations whose location has been plotted upon the working sheet and which are most favorably situated with relation to one another for an accurate "fix" by the three-point method. Next release the tracing paper and lay it upon the working sheet in such manner that the lines just drawn are superposed on the plotted positions of the respective observed stations, as would be done with the arms of a protractor; then prick upon the working sheet the position of the point originally assumed upon the tracing-paper, which will give the location upon the sheet of the occupied station. Finally unclamp the table, orient it upon some plotted station, and draw resection lines from one or more other stations for the purpose of verifying the determination.

42. Accuracy.—While it must never be expected that the results of plane-table work will be as exact as those given by computations based upon measured angles, the instrument is nevertheless capable of sufficient accuracy for a large variety of observations; in a careful survey its principal value is in delineating the topography, while in a hasty survey covering a limited area it will be found satisfactory for the main triangulation. In view of the importance of the working sheet as the

only record of observations, linen-backed paper should be used and every care taken to preserve it from moisture and changes of temperature. The lines should be drawn close to the edge of the rule with a hard pencil having a sharp chisel point; they should be of no greater length than necessary, and each should be appropriately marked to indicate its significance; as, at every station occupied, lines are drawn by prosection to all visible objects required to be plotted upon the chart, confusion will readily result from neglect of these cautions.

THE TELEMETER OR STADIA.

43. The Telemeter or **Stadia** affords a method of measuring distance which may be relied upon for close approximations to accuracy within the limits of its applicability. It consists of two horizontal cross-wires placed in the focus of the telescope of a theodolite, transit, or plane table, one above and one below the central horizontal wire, which are used in conjunction with a graduated rod held at the point whose distance from the telescope is to be measured. It is evident that, to an observer viewing the rod through a telescope so fitted, the number of graduated divisions subtended between the wires will vary with the distance, and that (regarding the telescope, for purposes of illustration, as a hollow tube) the length of rod included in the view between the wires will bear a direct ratio to its distance from the eye of the observer; that is, if 10 divisions are seen at a distance of 100 feet, then 20 will be seen at 200 feet, etc.

44. The Wires.—There are two methods adopted in the practical application of this principle, in the first of which the horizontal wires are immovably installed in the telescope, while in the second they are made movable. In the first method, which is generally to be regarded as preferable, the separation of wires is such as to give a convenient ratio of distance removed to length subtended on the rod; a value fre-

quently adopted for this ratio is 100, so that, whatever the scale, if a decimal system of graduation of rod be adopted the distance may be readily deduced; in such case, for example, a reading of 3.67 on a rod graduated in feet would correspond with a distance of 367 feet, while 1.21 on a meter scale would equal 121 meters.

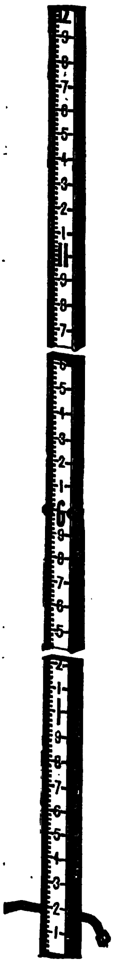


FIG. 9.

In the second method, the degree of separation of wires is adjustable, and the ratio becomes variable and under the control of the observer; as before, however, distance is equal to the scale reading multiplied by the ratio.

45. The rod (fig. 9) is generally made up of two pieces of wood, each about 6 feet long and 2 to 3 inches wide; the two parts are connected by a hinge, with stiffening piece, which permits opening to a single length having a continuous graduation. The scale divisions are usually painted in black upon a white face, with numerals corresponding to the main graduation (feet, meters, etc.) in red and to decimal subdivisions in black. In some rods, to facilitate reading at a distance, geometrical figures are substituted for the ordinary scale graduation, and attachments are sometimes provided by means of which the rodman is enabled to keep the rod in an exactly vertical position—a necessary condition for accurate results.

The graduation may be in any units of measure, but it is evident that it will be most convenient to use a rod graduated in the same units as are to be adopted for the plotting of the work—usually feet or meters. A rod may easily be constructed upon which any setting of the wires may be made to give readings in any desired measure of length. Thus, if it be required to construct a rod to read

meters with the wires of a given telescope, lay off 50 meters accurately by tape or otherwise, upon level ground, center the instrument over one extremity of the line, and hold an unmarked rod at the other; mark carefully upon the latter the points of intersection of the two wires, divide the interval into 50 equal parts, and graduate the whole rod in divisions of the same length; then the number of such divisions subtended at any position will be the number of meters of distance corresponding to that position.

46. It has thus far been assumed that the distance of the rod varies directly with the length subtended, as would be the case with wires in a hollow tube, the observer's eye being at the center of the station; the necessity of dealing, however, with the refracted ray of a telescope renders necessary a slight modification when seeking precise results, though the departure from accuracy due to the assumption referred to is never great enough to take account of in practice, except in special cases.

To treat the matter rigorously, the length of rod subtended varies directly as the distance measured, not from the center of the instrument, but from a point at a distance in front of the object-glass equal to its focal length. Hence, every reading should be corrected by the addition of the correction $c + f$, in which c is the distance from the center to the objective, and f the focal length. This correction is constant for any given instrument, and should always be determined and furnished by the makers; but, as it never attains a value greatly in excess of 1 foot, it is, as has been said, usually negligible.

47. If, in a telescope fitted with a vertical arc or circle, the angular elevation or depression be recorded at the same time as the stadia reading, data will be afforded for ascertaining the difference in altitude of the two stations, as well as their distance apart. Tables giving the required solution by inspection are usually furnished with stadia instruments.

48. The method of use of the telemeter or stadia will be

apparent. An observer occupying a given station directs the rodman to proceed to some point whose position is to be established, and the latter holds the rod in an exactly vertical position; the observer notes the direction as referred to some other established line of the survey, and also the distance; these are recorded, in the case of transit work, or laid down upon the sheet if using a plane table. The distance at which this method of measurement can properly be employed varies with the power of the telescope and the character of work in hand; it should never exceed 1200 feet.

While the telemeter may occasionally be used for base-line measurements (art. 89), it is principally of value for the delineation of topographical features.

49. The sextant may be employed for measurements of distance on the principle just described, and may be found a convenient substitute where no properly fitted telescope is provided, or where stations are occupied at which instruments

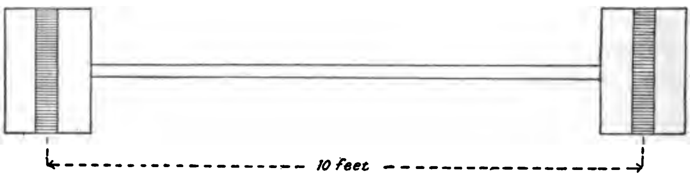


FIG. 10.

carrying a telescope cannot be set up; when so used, the rod is made of fixed length, while the variable angle corresponding to the distance is read with the sextant, being preferably measured "on and off" the limb when small. The rod, which may be made on shipboard, should take the form shown in figure 10, and may be of any desired length; ten feet will be found not too long for convenient handling. The extremities are marked by square white targets, bearing vertical black stripes of equal width whose centers are separated by the exact dis-

tance adopted for the base length; it is evident that if these two stripes are brought into coincidence in the direct and reflected rays of the sextant the angular distance between centers will be measured on the limb. To facilitate work, a table may be constructed in advance, giving the distances corresponding to various angles for the length of rod in use. Such a table will be found in Appendix I for a 10-foot rod, and this

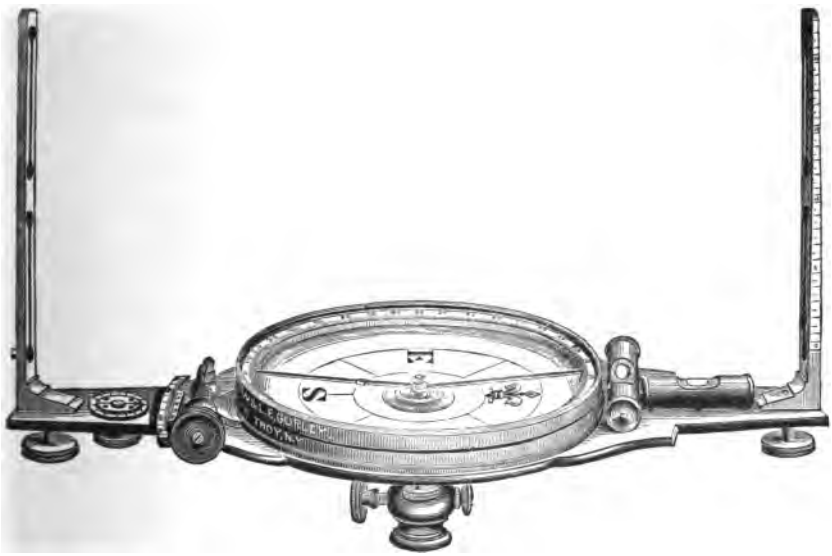


FIG. 11.

may readily be adapted to any other length by remembering that for a given angle the distance will vary directly as the length of pole.

THE SURVEYOR'S COMPASS.

50. The Surveyor's (or **Vernier**) **Compass** (fig. 11) may be regarded as a simple form of theodolite. It can be quickly set up and easily transported, but should not be used for ob-

servations requiring great precision. It consists of a magnetic needle contained in a case similar to that described as fitted to a theodolite (art. 17), which is carried upon a ball and socket bearing mounted on an iron-shod staff; the line of sight is established by a pair of vertical sight-vanes placed on an extension of the axial line; two levels are attached to the plate; an index dial is also attached thereto for convenience in keeping tally of the number of fleets made with a chain or other measure. By means of a tangent-screw, the compass dial is made movable in azimuth within certain limits, the amount of such movement being measured by an attached vernier; this device may be employed either for making exact readings of magnetic bearings or for turning off variation so that the needle may indicate true directions.

51. To use the surveyor's compass, it should be set up firmly, leveled over the occupied station, and the vernier properly set; the sight-vanes are then directed successively toward the objects to be observed and the directions recorded. A comparison of the bearings of any two points will obviously give the angle between them. The instrument may be used for alignment in making measures with chain, tape, or wire, and in some cases may advantageously replace the mariner's compass for taking bearings from small boats.

THE Y-LEVEL.

52. The Y-Level (fig. 12) consists of a telescope containing cross-wires, mounted upon the usual tripod with leveling-head, and thus capable, through the indication of an attached bubble-level, of having its axis of collimation brought to the true horizontal; in this position it is adapted to the precise measurement of differences of elevation. The telescope, which is longer than that ordinarily employed for the theodolite, is mounted in a Y-shaped carrier having motion about a vertical axis controlled by the usual clamp and tangent-screw; it has

no motion about a horizontal axis and no scale for measurement of motion in azimuth. The parts of the telescope tube which rest in the Y's consist of two metal rings turned perfectly to the same diameter; these fit in the Y's in seats provided with clamps, the arrangement being such that the telescope may either be made immovable, or rotated about a longitudinal axis, or shifted end for end.

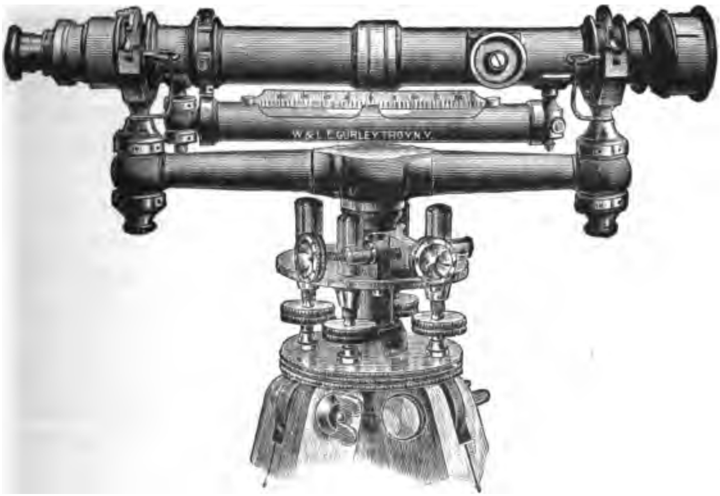


FIG. 12.

53. The adjustments to the level are made for the purpose of fulfilling the following conditions:

(*a*) *The line of collimation must be coincident with the axis of the imaginary cylinder which joins the two circular bearing surfaces of the telescope tube.* Set up the instrument firmly, bring it to an approximately level position, and focus the telescope upon some well-defined point at a distance of 200 to 300 feet, observing the usual care that the cross-wires are in the same focus. Bisect the object with the horizontal cross-

wire, using the leveling-screws, if desired, for bringing it on in elevation; then rotate the telescope through 180° about its longitudinal axis, and observe whether the object is still bisected; if it is not, correct one-half the error by vertical motion of the cross-wire diaphragm, bring it on again with the leveling-screws, and repeat the test. The horizontal wire being thus in adjustment, proceed similarly with the vertical wire, making any necessary correction by horizontal motion of the diaphragm.

(*b*) *The bubble-level attached to the telescope must be parallel to the line of collimation and in the same vertical plane.* Clamp the instrument over one of the pairs of leveling-screws and, the level-vial being at its lowest position, bring the bubble to the middle of the tube; then rotate the telescope a few degrees about its longitudinal axis; if the bubble departs from its central position it is an evidence that the axis of the level-vial when at its lowest position is not in the same vertical plane as the line of collimation. Level-vials on Y-levels are fitted with screws which, at one end, effect adjustment in a horizontal, and at the other in a vertical direction. Correct one-half of the error now developed by the horizontal motion and the other half by the leveling-screws, and repeat the process until satisfactory. Now, the bubble being central, lift the telescope from its Y's and replace it in a reversed position; if the bubble does not remain in the middle correct one-half by the vertical adjustment of the vial and the other half by the leveling-screws, and verify.

(*c*) *The line of collimation must be perpendicular to the vertical axis of the instrument.* Place the telescope in line with a pair of leveling-screws and bring the bubble to the middle. Revolve in azimuth through 180° about the vertical axis and note whether the bubble remains central; if it does not, correct one-half by the adjusting-nuts attached to the Y's (which give vertical motion to the telescope and attached

bubble-vial as a whole), and then complete the correction by the leveling-screws. Repeat as usual, then bring the telescope over the other pair of adjusting-screws and confirm adjustment.

54. To use the Y-level, set up the tripod, place the telescope in line first with one and then with the other pair of leveling-screws, centering the bubble in each case and finally verifying by noting if the correct level is indicated throughout a complete swing in azimuth; then focus. The rodman or assistant proceeds to the first of two points whose difference of level is to be measured and holds vertically upon the station a graduated staff, or *leveling rod* (fig. 13) carrying a conspicuous mark of adjustable height called the *target;* under direction of the observer the assistant moves the target until it is bisected by the horizontal cross-wire; the height of the target, which represents the vertical distance of the first station below the line of collimation, is then read by a vernier; the observer then proceeds to the second station and the operation is repeated. The difference of the two readings is evidently the difference in elevation.

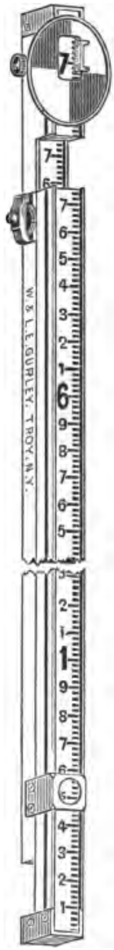


FIG. 13.

In measuring considerable differences of elevation several shifts of the instrument are made, any convenient intermediate points being chosen as auxiliaries. When long sights are taken, the distance from the instrument to each station should be made approximately equal, in order to eliminate the effects of the earth's curvature.

55. There is comparatively little employment of the Y-level in marine surveying; it is always valuable, however, in "leveling up" from the tide gauge to the bench mark, and may be utilized for

determining elevations and contour lines when time permits. Its place may be taken, in case of necessity, by an accurately leveled theodolite or plane table.

THE SEXTANT.

56. The Sextant finds very extensive employment in hydrographic surveying. Its construction, adjustment, and method of use are assumed to be familiar to all persons who will be engaged in that class of survey work.

57. Uses.—One of the most important uses of the sextant is for the measurement of horizontal angles for the rapid and frequent determination of the position of boats engaged in making soundings. For this purpose a special form of instrument, called a surveying sextant, is manufactured, differing from the ordinary type employed in navigation in being of lighter weight and having a smaller radius and longer limb; moreover, the telescope has a larger field, and the clamp and tangent-screw are arranged for convenient handling in a horizontal position; the vernier reads to half minutes only.

Besides its use in sounding work, the sextant may be employed for measuring the angles of the triangulation where no theodolite is provided; it is also generally used in the astronomical observations for latitude and longitude.

MINOR INSTRUMENTS.

58. The Heliotrope and **Heliograph** are occasionally employed as auxiliaries in survey work. They are instruments for reflecting a ray from the sun toward any given point, and are used to indicate to an observer at one station the position of some other station too distant to be otherwise recognized. They assume varying forms, and when not supplied it is easy to improvise a substitute.

59. The Three-Arm Protractor, or **Station Pointer** (fig. 14) used in surveying is of the same type as that employed in navigation, and its construction and use will be assumed to be

fairly familiar. Briefly, it consists of a circle having a limb graduated to right and left from 0° to 180° in each direction; it has three arms or rules, of which the middle one is fixed

FIG. 14.

and constitutes an extended radius of the circle along the line of zero graduation, while the other two are movable, being pivoted at the center, with attached verniers by which they

may be placed at any angle to right or left of the middle arm; there are facilities for indicating or marking the exact center of the circle upon the working sheet beneath the instrument.

60. By the method of the *three-point problem,* an observer occupies a point and measures the angles subtended thereat between the right hand and left hand pairs of three objects of determined position; these angles are laid off to right and left upon the three-arm protractor, and that instrument is so placed upon the chart that the edges of the arms pass through the plotted positions of the respective objects; then the position of the observer is at the center of the graduated circle.

61. The correctness of the graduation of the scale of the instrument should be tested; this may be done by noting whether the scale reading is zero when the edges of the rule are in coincidence (which it is possible to observe on one side only), whether a continuous straight line is drawn by two arms set at 180° apart, and whether, when set at given angles, the positions of the arms agree with lines exactly laid down at the same angles by chords or standardized protractor.

62. Various instruments have been devised upon the same principles as the one described but of simpler and less accurate construction; they are generally lighter, cheaper, and require less careful handling, and may be conveniently employed in work where more or less approximate results will suffice.

63. When no protractor is at hand, positions may be plotted by laying down upon tracing-paper (or linen) three lines at the required angles having a common vertex; the paper is laid upon the chart and these lines are superposed on the stations and the vertex pricked through. This method may be extended to include the simultaneous laying down of three or more angles, for the verification of the correctness of observation relating to the position of either the occupied station or of other stations previously plotted.

64. The Beam Compass is of frequent use in chart construction, taking the place of compasses or dividers where the span

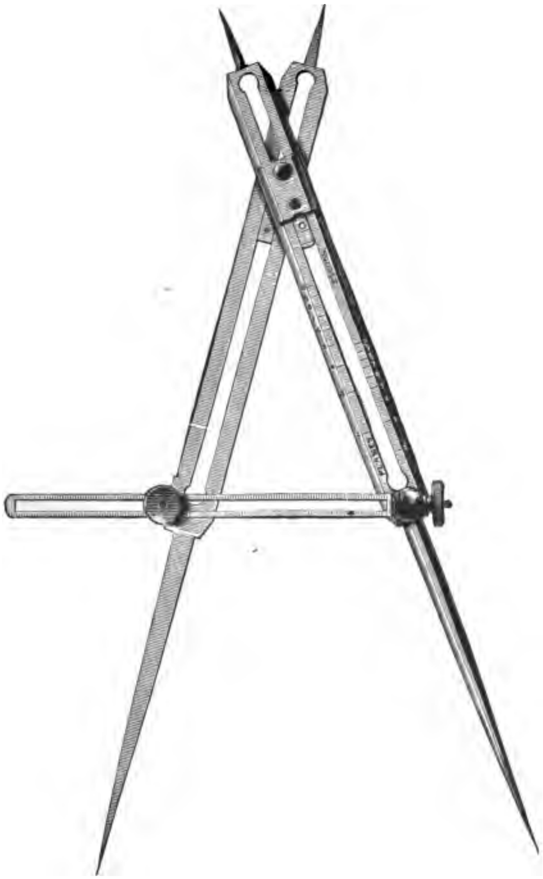


FIG. 15.

is too great for those instruments. It consists of a long bar, or *beam,* upon which are two traveling *heads* carrying sockets

for receiving either needle, pencil, or pen points; these heads are capable of being set at any given distance apart by means of clamps and slow-motion screws, the beam itself being graduated and a vernier provided.

65. Proportional Dividers (fig. 15) are employed in drafting for converting distances from one to another scale. They consist of two legs, each pointed at both ends like ordinary dividers, and pivoted at an intermediate point of their length to make an X-shape; the position of the pivotal point is made movable, and thus the span of the bottom pair of legs may be made greater or less than that of the top pair for the same opening; but, the pivot being set at any point, the span of the bottom pair at a given opening will always bear a fixed relation to the span of the top pair for the same opening. The travel of the pivot being graduated, it may be set, by the aid of a table which is provided, for any desired ratio of conversion; thus distances taken off with one end of the instrument are immediately converted to the other scale by laying down the span indicated by the opposite ends of the divider legs.

CHAPTER III.

BASE LINE MEASUREMENT.

66. In a hydrographic survey, the base line is ordinarily the only distance directly measured, all other distances being derived from triangulation based upon that measurement. As a result, therefore, an inaccuracy in the measurement of the base is carried through all future work.

The triangulation merely establishes the distance between any two points in relation to the length of the measured base, and a variation of *n* feet per 100 in that measure will produce an error of *n* per cent in every distance shown on the resulting chart. Thus, if a base line of 2000 feet contains an error of measurement of 10 feet, or .005 of its length, every distance on the chart will be in error about 30 feet for each nautical mile.

67. It will be apparent that accuracy of base measurement becomes more essential as the field of survey is extended. Taking the example just given, if the survey is one of a small harbor whose farthest station lies no more than one mile from the base, the error of 30 feet in its longest line would not affect the value of the chart for navigation work; but if the same base line were expanded by triangulation for 50 miles along a coast, the error of one-quarter mile in the farthest plotted position is much too great to be admissible.

For like reasons, the base should be of the greatest practicable length, for then a given error of measurement results in a smaller percentage of the whole. The ideal method, if practicable, would be to make actual measure of the distance between the two most remote stations; in this case an existing

error would appear in diminished form in the distance between any other two points, instead of being expanded, as is the case when the base is one of the shorter lines of the triangulation.

68. The conditions to be sought in the selection of a base line are the following:

(*a*) It should be of the greatest possible length capable of exact measurement, having regard to the quality of intervening ground and the method to be employed.

(*b*) The extremities must be visible from one another and from at least one other main triangulation station, the requisite observations for triangulation being impossible if this condition is not fulfilled.

(*c*) It should be so located as to form well-conditioned triangles or quadrilaterals with neighboring triangulation stations, of which as many as possible should be visible from its extremities.

69. The methods of base measurement employed in hydrographic work, in general order of accuracy, are: (*a*) by *tape;* (*b*) by *chain;* (*c*) by *sounding-wire;* (*d*) by *telemeter;* (*e*) by *masthead angle;* (*f*) by *sound;* (*g*) by *astronomical determinations.*

The base-measuring apparatus used for surveys of a special nature, while affording the most accurate of all measures, would never be employed in a hydrographic survey and need not be described.

70. As a preliminary to any measurement, the selected line must be sufficiently cleared of any brush or other growth that would interfere with sighting from end to end or with making the measure by the method adopted.

71. It is a general rule, applicable to all methods, that, the base having once been measured in one direction, it should be remeasured proceeding in the opposite direction, the mean being taken in case of a close agreement, or a third measure made if a material discrepancy is apparent.

72. The measurement by tape, chain, wire, and like methods requires a number of fleets, or shifts, of the measure along the base line, and this involves (*a*) the accurate marking of the termination of each fleet in order that it may be made the origin of the next, and (*b*) the alignment of the front or farther end of the tape at each fleet, to insure its being directly on the line. The methods of marking the ends of the fleet vary and will be described later.

73. The alignment is usually accomplished by an observer setting up a transit or vernier compass at the end of the base from which measurement begins, directing the line of sight upon the station at the other end, and establishing the line at any intermediate point by bringing into the line of sight a pole or staff held vertically by an assistant who moves right or left in accordance with signals; when the distance becomes too great for signaling, the instrument is shifted and set up over the last position of the pole, and the alignment continued from there.

74. A simpler method of alignment by means of two poles is nearly as accurate and dispenses with the use of the instrument. The first pole is set up on the line between the two stations by the eye, the observer standing at a point on the extension of that line; then, after the first fleet, a second pole is established on the range of the first pole and the base station from which measurement began, the alignment being afterwards verified by sighting ahead from the first pole to the farther base station; the second pole being now on the line, the first is moved ahead and established by the front and back range from the second pole; and so on.

75. The measurement by tape, when properly conducted, affords results of almost perfect accuracy, and should be employed where practicable. Tapes for this purpose (fig. 16) are made of different lengths, those of 100 feet being best adapted for the methods to be described; they consist of a thin ribbon

of metal—steel, or an alloy of steel and nickel—about one-half inch wide, which may be wound up in the same way as an ordinary linen tape; intermediate graduations are marked along their length and the ends are appropriately finished—the details as to these features differing according to manufacture.

76. Before use, tapes should be compared with a standard for verification of their accuracy; those furnished for United States naval survey work are first submitted to the Bureau of Standards, which furnishes a certificate stating the true length between specified marks on the tape when supported throughout its length, at a given temperature and under a given tension, as well as the variation that may be expected per degree of difference of temperature; the true length between the extremities may thus be known under conditions of use.

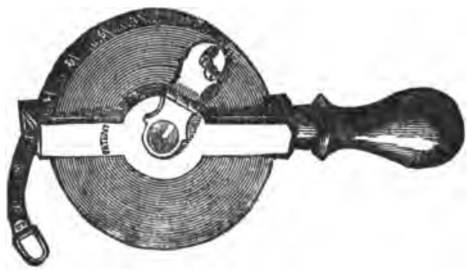


FIG. 16.

77. Every precaution must be taken for the care of the tape. After use, it is almost certain to be wet—frequently with salt water—and if put away in that condition is liable to rapid deterioration and breakage; it should therefore be immediately wiped off, freed from rust, and kept either coated with or immersed in oil until next required.

78. To insure precise results, the tape should be supported throughout its length in a truly horizontal position during the measurement of any fleet; for this purpose the following

should be provided: four battens of seasoned wood, each $25\frac{1}{2}$ feet long, of which the cross-section is an equilateral triangle of 3-inch sides; about two dozen pointed iron rods, each with a crutched head having horns at an angle of 60° to receive the battens, the length varying from 2 to $4\frac{1}{2}$ feet; a sack full of wooden pegs about 1 inch square and 8 inches long, in the top of each of which is a copper tack with score filed across its head; about 150 feet of heavy cord or cod-line; a hand-level or carpenter's level; two plumb-bobs; aligning poles; hand axe for driving pegs and chopping, and machetes for clearing brush; small spring-balance; thermometer; and the tape. The plan is to carry the battens horizontally in the forked rods in a continuous line a little longer than the tape, making a table along the base line upon which the tape may be laid.

79. The line is first established by stretching taut the cord on the ground in the alignment marked by the pole. Then the first and last crutched rods are driven into the ground adjacent to the cord and a few feet within the ends of the first 100 feet, and the bottom points of their two forks are adjusted to the same level by sighting with the hand-level and driving in or withdrawing one or the other rod; the cord is then lifted into these forks and a straight level line is established in the direction that it is desired to measure; the remaining forks—three in all for each batten—are now driven in, the bottom of the fork in each case being in contact with the cord but not deranging the line that it marks; then the cord is taken out and the battens laid in, closely abutting one another and overlapping the ends of the fleet.

Another method of placing the battens is to drive in all the forked rods adjacent to the cord as it is stretched upon the ground and place the battens in them; then let an assistant with a carpenter's level start at the rear batten and work along the line, adjusting the rods as may be necessary to bring the battens truly horizontal.

The tape is now laid flat along the battens, and an observer with a plumb-bob goes to each end (the plumb-bobs used in this work being sharp-pointed and suspended by thread); the proper degree of strain, as indicated by a spring-balance hooked into the forward end, is put upon the tape, which is so adjusted in position that a plumb-bob hanging downward in coincidence with the 100-foot mark at the rear end is exactly over the score in the tack which marks the rear station; then a peg is driven into the ground at the front end and worked into such position that a plumb-bob from the zero falls upon the score of its tack (the latter being always placed crosswise to the line); this condition must be fulfilled at a moment when the spring balance shows a tension equal to that for which the tape is standardized—usually 15 pounds. The temperature of the tape is read and recorded, being obtained, preferably, from two thermometers—one affixed to the tape at each end; a fleet is tallied independently by two persons; and the tape is released and another fleet begun.

The forked rods should always be driven alongside the cord on the same side, and the plumb-bob and pegs should always be placed on the same side. The pegs are left in the ground, not only as a means of rectifying a mistake in tallying the number of fleets, but also of repeating any part of the work without going over the whole. The fractional fleet at the end is measured by a similar method to a whole fleet, if the graduations of the regular tape permit, or by a tape provided for the purpose if the former has not the finer graduations.

Two measurements having been made, each should be corrected for temperature and the results compared. The probable error by this method is not over .00005 of the measured length; thus, in a base line 5000 feet long, each measure should vary not more than .25 foot from the mean. In the matter of speed, about twelve fleets an hour may be expected when the party gets to working together, as it will soon occur

that each member falls into the routine performance of his own share of work, and the various steps follow one another without delay.

80. A modification of the foregoing method, in which the use of the battens is dispensed with and the tape laid directly upon the ground, may be adopted where the character of the ground passed over is even enough to justify it and the triangulation is not to be extended over too long a distance; across a sandy beach or a level plain this method will yield almost as accurate results as when battens are employed, and there will of course be a great gain in speed. To mark the ends of the fleets by this method two or more boards are prepared, having approximately a length of 2 feet, a width of 4 inches, and a thickness of ¾ inch, with a fine mark or score across the center in a direction at right angles to the longer dimension; the tape having been laid along the line as marked by the cord and being held fast with its 100-foot mark over the origin of the fleet, the proper tension is put upon it, and one of these boards is placed under the forward end with its score directly under the zero of the tape, and held in place either by an assistant standing firmly upon it or by means of pegs driven down at its front and rear ends; the fleet is then tallied and the tape shifted forward until the 100-foot mark comes over the score, when the operation is repeated and another board placed at the forward end. In the practice of this method, it may be expedient, when a fleet crosses a depression in such manner as to leave the tape unsupported during a material part of its length, to improvise intermediate supports from stakes (art. 81) placed at the proper height at several points along the line.

81. Another modification of the first method may be adopted to avoid the use of battens, which is available even though the ground is not favorable for furnishing directly a horizontal support for the tape, the results given being but

slightly less accurate than where battens are employed. In this method, the tape is supported only at intervals; stakes are generally brought into use for furnishing such support, and they should be driven into the ground at distances of about 10 yards apart; the stakes at the end of a fleet have a tack with scored head, or similar mark, in the top as a reference point; intermediate stakes may conveniently carry the tape upon a nail driven into the side, the latter being placed at such a height as to perfect the vertical alignment between the end supports. Differences of level between the two ends of each fleet must be carefully observed in order to effect a reduction to the horizontal in uneven ground.

82. Temperature corrections have a material value in all measurements with common steel tapes, and must be carefully heeded. When such tapes are used in the rays of the sun special precautions must be taken to avoid constant errors in the determination of the temperature of the tape which, when mercurial thermometers are used, may amount to as much as 5° Fahr. and produce constant error as great as .00003 of the length; for this reason, measurement with such tapes should, when practicable, be made on overcast days. Tapes manufactured from an alloy of steel and nickel called "invar" have a coefficient of expansion so small as to be practically negligible for temperatures ordinarily encountered in base-line work; with these, daylight measurements may be made without reference to the effect of sun or clouds.

83. The measurement by chain can be made much more rapidly than by tape, but only approaches the last-named method in accuracy when the ground to be passed over is of a very level character. The chains used for the purpose (fig. 17) vary in length, material, and details of construction; the length of 100 feet is most convenient for hydrographic surveys, and steel wire is the preferable material on account of its strength. The 100-foot chain is provided with 100 links,

each link of exactly one foot length, excepting the two end ones; the end links proper are shorter than the rest, but the deficiency is made up by the handles, the latter being attached by a screw which permits of variation of position and consequent adjustment of the total length to a given standard, a lock nut rendering the handle immovable upon the thread when once adjusted. Every tenth link is marked by a brass tally bearing the appropriate number of notches to indicate its distance from the end. With every chain there are provided ten or more marking-pins; these are made of iron, steel, or brass wire, and have a point at one end for being pushed into the ground, with a ring at the other to facilitate handling.

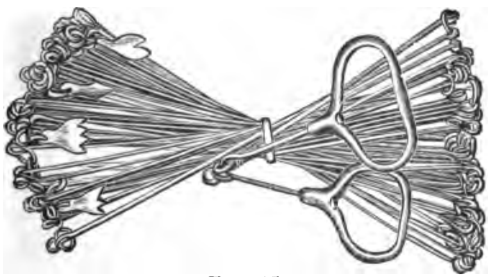


FIG. 17.

84. Before use, a chain must be compared with a standard and either its length adjusted to 100 feet or the length of one fleet determined; this is not only to correct possible errors of manufacture but also to adapt the length to the particular method of measurement employed. To this end, a distance of exactly 100 feet should be laid off, preferably by a standardized tape, upon a ship's deck, sandy beach, or like level surface. It must now be decided which method is to be employed for marking the ends of the fleets—whether the marking-pins are to be placed in the ground (*a*) adjacent to the outer edges of the handles, or (*b*) adjacent to the inner edges of the han-

dles, or (*c*) adjacent to the outer edge at one end and the inner edge at the other. This having been determined upon, stretch the chain along in such manner as to afford comparison in accordance with the method selected for the use of the marking-pins, keeping in mind the principle that the true value of a fleet is the distance between the axes of the pins. For example, if the second method is to be adopted, one pin should be placed directly over one of the standard marks and the inner edge of one of the handles placed against it; then the chain should be stretched taut in the direction of the second mark and a second pin placed at the inner edge of the other handle. Come up the chain and pins and note the position of the center of the hole made by the second pin with reference to the second standard mark; if the agreement is not perfect the chain may be shortened or lengthened to the necessary amount by the adjusting-screws; or, if preferred, the excess or deficiency of length as compared with the standard may be measured, and, having been added to or subtracted from 100 feet, the resulting value should be used as the length of a fleet in determining the result of any measurement.

Since measurements by chain are not ordinarily corrected for temperature, the comparison should preferably be made at appoximately the temperature of prospective use. As a chain is apt to undergo an extension of length from various causes incidental to use, the comparison should be repeated from time to time.

85. For proper preservation of a chain, as of a tape, it should be kept free from rust and, when not in use, well coated with oil.

86. Measurements with the chain are made according to the general principles governing those by tape. One man carries the front end of the chain together with ten marking-pins; to each of the pins is attached a small piece of sheeting or bunting—to nine of them of one color and to the tenth of another

color, as white and red, respectively. The chain is laid out along the line, straight and free from kinks; a pole is carried to a distance a few feet short of where the end of the chain is expected to reach, and aligned approximately by the man who carries it, the alignment being verified from the other end, a second pole being held upon the base station to facilitate this; then the chain is stretched taut along the line marked by the pole, its rear end held in proper position with reference to the adopted method of measurement at the base station; a pressure of about ten pounds (by estimate, not by scale) is then put upon the front end, and a white marking-pin placed in proper position at this end. Then the party shifts forward; the alignment is repeated, using another pole and sighting by the eye alone; the rear end of the chain is held in proper position with reference to the white pin marking the end of the first fleet, pressure exerted as before, and a second white pin planted at the front end; before making another shift forward, the first white pin is picked up by the man at the rear of the chain. The tenth fleet is marked by the red pin, and when the rear man comes up with this, he should find that he carries nine white ones; a means is thus afforded of checking the tally of the number of fleets; the pins are again sent ahead to the front end, and the front and rear men independently keep a tally of the number of 1000-foot lengths thus completed.

Fractional fleets at the end may be measured either by the chain, remembering that one link corresponds with a foot, or by a reliable tape.

If necessary, bases may be measured by two men—one at each end of the chain; but it will be better to detail at least two extra men for expediting alignment, sending pins forward, clearing the chain, and like duties.

When chaining under water, as is frequently necessary along a sandy beach that is not quite straight, the method should be

modified by having the two ends alternately circle around one another, instead of shifting the chain bodily forward. In this case, the measurement is made from the inner edges of the handles, the chain having been standardized accordingly; a pin placed to mark the front end of one fleet serves as a pivot around which the handle swings to become the rear of the next fleet; the pin and handle may not even be in view during the swing, but the pin should of course be steadied by the hand to avoid being drawn out of position by the strain, as would also have to be done on the dry beach.

87. Measurement by wire is the best method where neither tape nor chain is available, producing results of sufficient accuracy for a survey of moderate extent in localities where the nature of the ground is unfavorable for other methods. It consists in stretching a length of sounding-wire between two given points under such pressure and with such intermediate support as will insure a practically straight line; then the length of wire thus laid out is measured by the most convenient method.

The details of laying out the wire vary with the conditions and must be adapted by the surveyor to the particular circumstances. The principal consideration is that the line shall be straight; to secure this, it may be necessary to divide the measurement into several parts, reaching, respectively, from one to another of the highest intervening points, or crests, along the base line; where this method involves crossing a depression, the wire should be supported at intervals of not less than 300 feet by improvised trestles; if there is a difference of elevation from one to another point, the angle of inclination should be measured by the vertical circle of the transit and the length of the wire reduced to its equivalent on the horizontal. Measurements across water may be made by attaching cork or wooden floats to the wire at proper intervals.

The wire is laid out from a reel securely staked down on an

extension of the base line a few feet behind the station from which measurement begins; having been led along the line and exactly over the farther base station, the end of the wire is secured either to a natural object, as a tree, or to some object placed for the purpose, as a boat anchor; by reeling in, a strain is now put upon the wire, and when it lies taut and clear along the line a signal is made, whereupon seizings are put upon the wire at the two points in coincidence with the base stations; this operation may be repeated one or more times, taking in a little of the wire at the farther end before each repetition, and when the measurement of the wire comes to be made this will afford a check upon the accuracy and show whether the seizings have slipped, as the intervals between seizings at one end should correspond with those at the other.

It now remains to measure the distance between seizings at the two ends and this may be done in various ways. One method is to reel up the wire under proper tension, passing it over an intermediate reel, and keeping count of the number of turns and final fraction of a turn made by that reel, which, multiplied by the circumference of the reel, gives the length. If the main reel is one used for deep-sea sounding and is standardized for increased diameter corresponding to any given number of turns, the intermediate reel may be dispensed with. Another method is to measure the wire between marks on the deck or beach, or by means of a tape, always taking care to see that it is under proper tension during the operation.

88. In the absence of sounding-wire, the best possible substitute may be improvised. A deep-sea lead line, for example, might be used, but care would have to be taken that the tension under which it was laid out agreed exactly with that of measurement, and even so the result could not be considered exact.

89. Measurement by telemeter affords a close approximation to accuracy, but should never be made the basis of ex-

tended triangulation; it would be appropriate only in the survey of a harbor when circumstances prevented measurement by tape, chain, or wire. The general method to be followed will be apparent from the description of the telemeter (art. 43). Since this instrument is much more accurate for short ranges than for long ones, it will be advisable to divide the base into several sections, selecting intermediate points in alignment and about 200 feet apart as auxiliary stations, between which measures are made. When employed for base-line measurement the $c + f$ correction should always be applied, and if there is a material inclination between any two stations, the elevation by vertical circle should be read and a reduction to the horizontal made.

90. For rough or hasty work, the sextant and pole (art. 49) may be employed for base measurement.

91. Measurement by masthead angle is an extension of the principle of measurement by telemeter, and is only employed for surveys of small extent. It consists in measuring by sextant from a point on shore the angle subtended by a ship's mast between truck and water-line, or any other two points; the distance between the selected points must be determined as accurately as possible, either from the ship's plans or actual measure, and if the water-line is used proper account must be taken of the existing draft. The distance may be assumed as equal to the height of mast multiplied by the cotangent of the observed angle; this assumption is exact only when the observer's eye is on a level with either the upper or lower point on the mast, but the error involved when this condition is not fulfilled is so small as compared with other probable errors that it may be disregarded.

92. The operation just described gives the distance from a point on shore to the ship; but the latter, having always considerable motion about her anchor, could properly be used as an extremity of the base line only on condition that all angles

of the triangulation to be measured to or from it were observed at the same moment as the observation for distance—an obviously inconvenient requirement. It is, therefore, preferable to use masthead angles as a means of determining the distance apart of two stations on shore which mark the extremities of the base line.

In figure 18, suppose that *A* and *B* are two such stations, visible from one another and from the ship, and so located as to form a favorable basis for triangulation. Place one observer at *A*, one at *B*, and one at *S*, at the foot of the mast whose altitude is to be measured, each being provided with a sextant. A certain signal, as the hauling-down of a flag, having been agreed upon for simultaneous observation, a moment is selected when the ship is steady and the signal is made; the observers at *A* and *B* each measure the masthead height, and then, as quickly as possible afterward, the horizontal angle between the other station and the ship, while at *S* the angle between *A* and *B* is measured. Several repetitions are made by signal; at each station a record of the time of each observation of the series should be kept by watches previously compared, to avoid confusion that would otherwise result in case either station misses a signal; or the same object may be accomplished by having each observer "acknowledge" signals by wigwag.

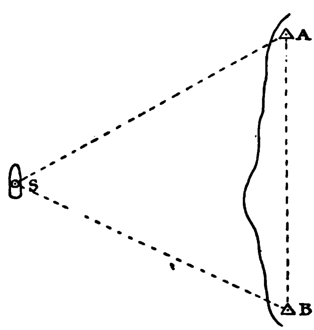


FIG. 18.

Taking any set of observations, add together the angles measured at *A, B,* and *S,* and if they do not exactly equal 180°, adjust each angle to fulfill the required condition by applying one-third of the excess or deficiency; then compute

the side *AS* from the vertical angle observed at *A*, and from this and the adjusted angles compute the length of base *AB*; for the same set, compute *BS* and thence *AB*, and compare the results, which will afford an evidence of the accuracy of the observations of angles, though an error in the assumed masthead height would affect both calculations alike and would not, therefore, reveal itself. Proceed likewise for other sets of observations, and take the mean of all values of *AB* as the final result.

93. Measurement by sound is a method of the crudest sort, and should never be adopted when any other is available; it will seldom occur that all other methods are impracticable, and only in such case should this one be employed.

The process consists in measuring the time required for sound to travel from one to another end of a base line, and, from the known velocity of sound, deriving the distance. The practical method is to place an observer at each end of the line, each provided with a firearm and a timepiece. A program being agreed upon, or arrangement made by signal, a shot is fired by one observer and the other notes the time elapsing between the visible flash and the audible report, such interval being the time required for the sound to travel over the intervening distance; several repetitions are made, and then the operation is reversed—the shot being fired from the opposite end of the line and the elapsed time measured by the observer who did the firing for the first series.

The method of measuring time must be the best one available. As it is improbable that a chronograph would be found in the equipment of a surveying party that would measure a base by sound, the next best instrument is the stop watch marking 0.2 second supplied to naval vessels; failing this, an ordinary watch could be used by counting the beats, of which there are several (the number easily determined) to the second.

Having determined the time for the sound to travel from one to another station, the distance is given by the formula:

$$d = n\{1090 + 1.15\,(t - 32)\},$$

wherein d = distance between stations in feet;
n = number of seconds of elapsed time; and
t = temperature of air in degrees Fahrenheit.

The expression within the brackets represents the velocity of sound in feet per second. The value assigned to n is of course the mean result of all the observations.

94. If we assume that the measurement of the time interval has no greater error than one-fifth of a second, there will still be an error in the resulting distance of about 220 feet, from which will be seen the roughness of the method, and the necessity of making the base of the greatest possible length so that a given error will, through being the smallest percentage of the whole, have the least effect.

95. Astronomical observations may be employed, in a survey of considerable extent, to take the place of a base derived from linear measurement. The method is to determine the geographical coordinates of two points as widely separated as possible and regard them as the extremities of a base line; the triangulation is then plotted, assuming any convenient scale, until the two points are connected, when the true value of the scale may be determined. Even if this method is employed, however, it is better to make it supplementary to the results derived from an actually measured base, so that the different determinations may afford a check one upon another (art. 101).

96. A modification of this method which may be employed when the stations are intervisible is to obtain either the difference of latitude or difference of longitude between them and observe the true azimuth from one to another; when latitude is employed, the stations should lie nearly upon the same me-

ridian, and in the case of longitude, nearly upon the same parallel. The method involving difference of latitude has the advantage of being independent of the chronometer error; but the absolute amount of that error is immaterial, so far as the base line is concerned, where longitude is employed, as it is merely necessary that the rate should be accurately known between observations—which emphasizes the expediency of taking the two observations within the shortest possible time of one another.

Computations of any data derived from this method must be made by the formulæ of Spherical Trigonometry, taking account of the earth's curvature.

97. Broken bases are those in which, circumstances preventing direct measurement between the base stations, the distance along auxiliary lines is measured, together with the necessary angles, and the length of the base derived by computation.

98. The most usual form is that shown in figure 19, in which *E* and *W* are the base stations whose distance apart is

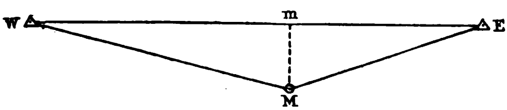


FIG. 19.

required, but which are separated by water or ground that can not be measured over. A station *M* is selected, visible from both *E* and *W*, and such that the angles made by *EM* and *WM* with the base line are very small. A signal is erected at *M*, and measurements made of *EM* and *WM*, following for each the same method as would be employed for a direct measure of a base; *E*, *W*, and *M* are also occupied and the angle at each between the other two measured with the greatest care; the angles are then adjusted by comparing their sum with 180°, and, using these adjusted values, the auxiliary lines are projected upon the base at *Em* and *Wm*, the sum of which projected distances gives the length *EW*.

Cases sometimes arise where it becomes necessary to employ two (fig. 20) or even a larger number of intermediate stations, the principle being the same in every case; and while each such break introduces a possibility of small error, it is better

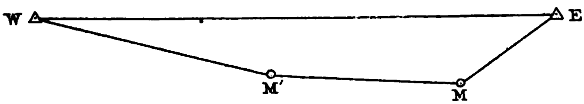


FIG. 20.

to accept that possibility than to expand the triangulation from too short a base, or from one measured over unfavorable ground.

99. Figure 21 illustrates a method of measurement of a broken base in which no computation is necessary for the reduction. Suppose the conditions to be as shown, an indented shore line, $SS'S''$, rendering impossible an uninterrupted measurement between the base stations E and W. Measure EA, stopping at A, on the shore-line, and marking the point by a

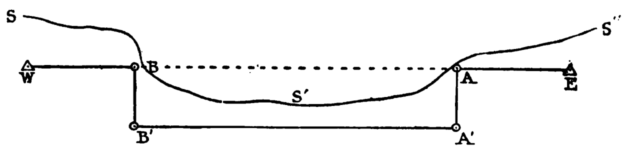


FIG. 21.

peg with tack having a scored head; set up a transit at A, sight back to E, then turn off 90° and align an assistant at some convenient point, A', accurately marking the latter in the same manner as was done at A; now occupy A', set the zero on A (holding some vertical object temporarily upon its tack to sight upon) and again turn off 90°, and measure upon this alignment to B', at which put another mark; next occupy B', sight along $B'B$ at right angles to $B'A'$ and place a peg with

tack at B, where the original base line is intersected, being assisted in the alignment by an observer with transit at W; finally measure BW. Since $AB = A'B'$, we shall then have:

$$EW = EA + A'B' + BW;$$

or the base equals the sum of the three measured distances. As an evidence of the accuracy of laying off angles, the distances AA' and BB' may be measured and compared.

100. It may occur that an otherwise practicable base line, as EW in figure 22, is interrupted for a comparatively short part of its length, AB, by a stream or other obstruction im-

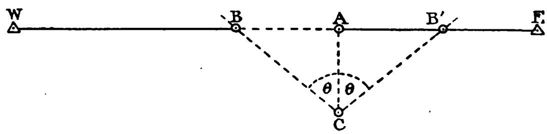


FIG. 22.

possible to measure across. Put pegs with tacks at A and B, the extremities of the respective sections of the base line, and occupy one of these, as A, with a transit; turn off 90°, and, the line of sight lying now along the line AC, mark some convenient point C on that line such that the distance AC is approximately equal to AB; next occupy C and measure the angle $BCA = \theta$; then, with the zero on A, lay off the angle θ to the right, and by the aid of an assistant at E mark the intersection of the line of sight with the base line at B'; then measure the two sections of the base, EA and BW, and, incidentally to the measurement of the former, determine the distance $AB' = AB$, the length of the unmeasured section; then,

$$EW = EA + AB' + BW.$$

The accuracy of the point B' thus determined may be verified by assuming one or more other positions of the point C lying in the direction AC. If the line AC is adapted for ac-

curate measurement, its length may be determined, and the result of the graphic method checked by computation from the formula:

$$AB = AB' = AC \tan \theta.$$

101. A check base is one measured between two points of which the positions have been determined by triangulation carried forward from the original base; in order to afford a verification of all work that has gone before, the most distant points of the survey between which accurate measurements can be made should be chosen. It is evident that if the original measurement and the intervening triangulation have been correct, the computed and the measured length between the stations should correspond; if such correspondence does not occur, the work must be reconciled; if the two base measurements are given equal value and the triangulation is not in doubt at one place more than another, each side is adjusted by an amount proportional to its distance from the origin of plotting; but if any weak point is known to exist in the observations the adjustment is modified accordingly, assigning to that point an increased proportion of the discrepancy.

CHAPTER IV.

SIGNALS AND THEIR CONSTRUCTION.

102. Every station of the main or secondary triangulation must be marked by a signal of some sort, in order that it may be distinguishable as a definite point in observations made from other positions. The considerations which should govern in the selection of the position of a signal and in its construction (the former being closely connected with the subject of triangulation) are as follows:

(*a*) Its position should be favorable for location from adjacent stations, and for assisting in the location of other stations;

(*b*) It should, in connection with other signals, cover a definite part of the field;

(*c*) It should be at the most favorable position in the neighborhood for an unobstructed view in all directions, as at the extremity of a point or on the top of a hill;

(*d*) Its size should be such as to make it visible from the most distant station from which it is to be observed;

(*e*) If marking a main triangulation station, it should be capable of having a theodolite set up at its center.

103. It is only occasionally that a natural object may be found fulfilling all these requirements, though a lighthouse may sometimes be made to do so if the illuminating apparatus is dismounted to give place to the instrument. For the most part, however, artificial signals have to be constructed by the surveyor, especially when required to mark main triangulation points.

104. The tripod signal (fig. 23) is extensively employed

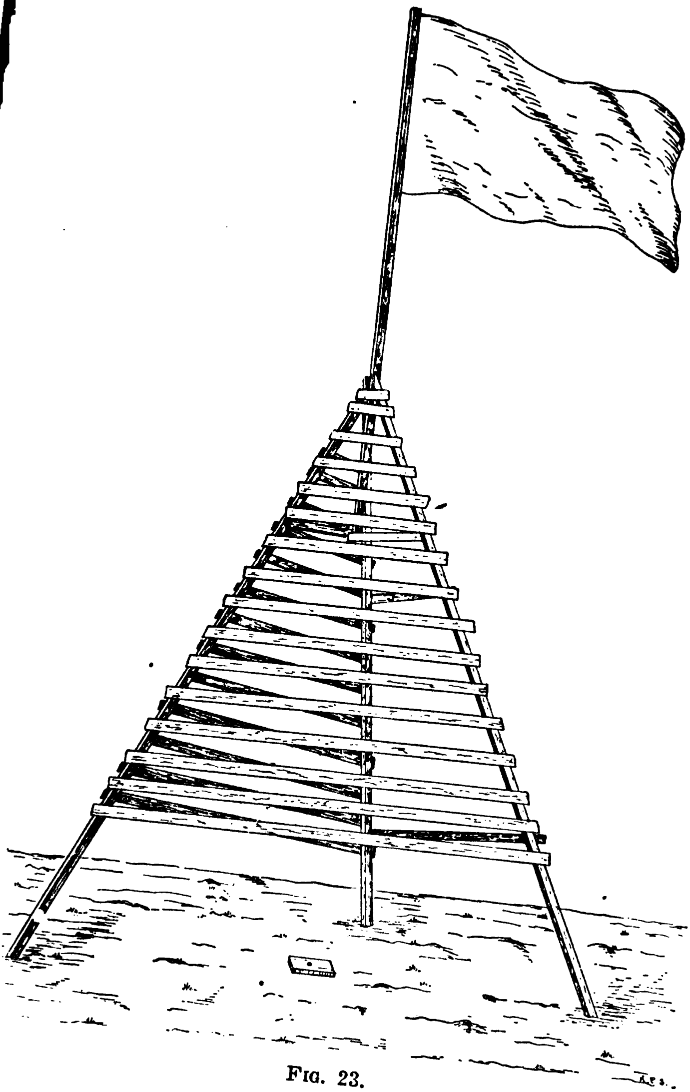


FIG. 23.

in careful surveys. It consists of three legs meeting in a point or apex from which rises a vertical pole; the sides are boarded up and whitewashed and a flag attached to the pole, making it visible for long distances, while the ability to set up a theodolite vertically beneath the pole permits the measurement of angles from its exact center. Such signals are, moreover, capable of being erected in a few minutes, and may be easily dismounted, when one part of a survey is complete, and transported to some other part for use again.

For legs and flagpole wooden scantlings are used. Up to 20-foot lengths, the dimensions should be about 2 by 3 inches; thence to 30 feet, 3 by 3; and for 40 feet, 4 by 4 inches; the length of flagpole is about two-thirds the length of a leg. For boarding, undressed lumber may be used, not less than $\frac{7}{8}$ inch thick and 6 inches wide; for boarding up a signal on two sides for three-fourths the distance from apex to ground, the number of square feet of boards required equals two-tenths the square of the length of scantling leg in feet; this rule applies for scantling legs set at an angle of about 60° to the horizontal, and for intervals between boards equal to their own width, though in case of shortage of boards this interval may be increased, with consequent saving of lumber. Bolts used for binding the scantlings together should be of $\frac{1}{2}$ inch diameter for lengths of scantling including 30 feet, and $\frac{5}{8}$ or $\frac{3}{4}$ inch for longer ones. A complete list of articles required by a signal-building party will be found in Appendix III.

In preparing to erect a signal, the scantlings are laid parallel upon the ground with overlapping ends, the two outer legs extending in one direction, and the middle one, together with the flagpole, in the other. Holes have previously (preferably on board ship) been bored about half a foot from the end of each leg, and one-fourth the length from the end of the flagpole, to take the bolt; the ends of the two outer legs have also been sawed to a bevel, just above the hole, of about 60°, in a

direction that will permit the spreading of the outer legs. The bolt, which has a head on one end and a screw-thread on the other, is now thrust through and set up with a nut with washer. The sheeting flag is tacked to the pole and bighted

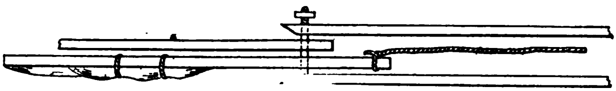


FIG. 24.

up, and a tripping-line made fast to the heel of the latter (fig. 24).

The two outer legs are then carried apart until they make an angle of about 60° with one another, the bolt being bent in the process (fig. 25).

The men then divide themselves, one going to the extremity of each outer leg, some to the point where the scantlings are joined together, and some to the extremity of the middle leg; the men in the middle lift until the apex rises a few feet above

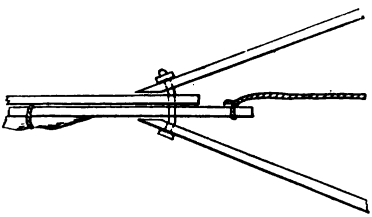


FIG. 25.

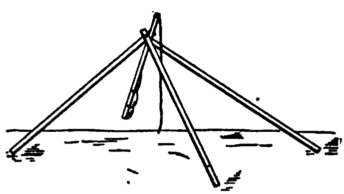


FIG. 26.

the ground, when the whole assumes a pyramidal form (fig. 26) and can be worked to any required height by pushing inwards on the middle leg and holding down on the two outer ones. Care must be taken during the first part of this operation, as it is easy to capsize the pyramid; but after reaching a certain height the frame acquires considerable stability and can be freely moved about into the exact position chosen.

The frame having been so placed that the two of its three faces which are to be boarded up will reflect light most favorably for visibility from distant points, and also so that no leg obstructs the view from the center toward any station which is to be observed, holes are dug for the extremities of the legs, and upon each of the latter are nailed cross-battens to form a resisting surface, or anchor; the legs are then buried and the holes firmly filled in. Judgment must be used in this operation, the depth of hole and form of anchor varying according to the character of the ground, the size of signal, and the winds to be expected; among rocks, the anchor may be weighted with a heap of stone; in coral, the heel may be shoved into a hole and secured; in sand, extra surface must be given to the anchor and extra depth to the hole; the first squall after the erection of signals by an inexperienced party usually carries with it some lessons, and even an ordinary afternoon trade breeze may have something to teach. At times rope guys form a very essential supplement for securing a signal.

The tripod being up, a piece of board is sawed into steps and nailed to the legs to enable men to reach high enough for nailing; boarding-up of the two outward faces is commenced at a height of about one-fourth the distance from apex to ground, and (for convenience of occupation) at never less than 6 feet from the ground; in boarding the two covered sides, intervals are left between boards about equal to their own width; on the third, or inner, side one or two boards should be nailed for structural purposes. Before the boarding has progressed far enough to prevent, the flagpole is swung to the vertical position by the tripping-line, and the flag released; short strips of wood are then nailed to its heel, pointing respectively toward the three tripod legs; two observers sight at the pole from directions at right angles to one another, each holding a plumb-bob between himself and the pole, and the

pole is moved until it appears to each perfectly vertical, when the strips are nailed to their proper legs and the pole thus secured in position (fig. 27). It is of the utmost importance to insure the verticality of the pole if accurate results are expected in the measurement of angles between signals.

When boarded up, the tripod is whitewashed. If short of boards, strips of sheeting are sometimes used as substitutes; when the tripod has a sky background, black sheeting thus used greatly increases the visibility; similarly, black or white or mixed flags must be chosen according to the background.

FIG. 27.

Finally, a plumb-bob is dropped from the center of the heel of the flagpole, and the exact center of the station determined, which must be appropriately marked for occupation with the theodolite.

105. It is seldom that a tripod with legs 40 feet long will not answer the requirements of the largest signal for hydrographic work; when, however, larger signals are needed, special structures must be built, which may take the form of quadrilateral towers with legs made up of scantlings in several lengths and strongly counterbraced.

106. Observing towers have occasionally to be employed, being constructed in positions where the surrounding foliage, or other obstruction to the view, requires that the theodolite be elevated to permit observation of the angles. An attempt to construct a platform at some intermediate height on an ordinary tripod will usually be found unsatisfactory, as the

shifting weight of the observer upon such a platform, no matter how solidly braced, is almost certain to derange the level of the instrument. The best method, under these circumstances, is to construct a tripod signal such as has been described, omitting the flagpole and finishing off the top with a small horizontal table large enough for carrying a theodolite set up upon its leveling-head; then to surround it with a quadrilateral tower built about the same vertical axis, but in no way touching the tripod, finishing the tower with a flagpole over the center and placing cross-pieces at such height as to enable an observer to stand upon them while using the theodolite without placing his weight upon the tripod.

Or a simpler method, where less height will suffice, is to complete the tripod with flagpole in the ordinary way and to build within it, but not in contact with it, a second tripod whose top shall form the table for the instrument, while the observer stands upon a board or platform attached to the legs of the outer tripod.*

107. The pole signal may be used for triangulation of moderate extent. An excellent form of this signal is constructed by driving vertically into the ground a piece of iron pipe about 2 inches in diameter and 2 feet in length; this forms a socket for stepping a light pole having a height above ground of 6 to 10 feet; to the top of the pole is attached a flag and immediately below this two pairs of guys are made fast, each pair consisting of a single piece of light stuff either hitched in a notched collar or secured by tacks at about the middle of its length, and the four ends set up to pegs driven into the ground; triangular pieces of sheeting tacked to the pole are stopped out to the guys, the whole giving the effect of a pyramidal target; black or white sheeting is chosen, according to the background. The guys can be quickly come up and the pole unstepped to permit the occupation of the station, the theodolite being set up with its plumb-bob over the center of

* Tripods and towers of wood may be replaced by those of metal for hydrographic signals. These are made of lengths of pipe coupled together and properly counter-braced, resembling the structures employed in modern practice for windmills. The parts are obtained, ready to put together, from manufacturers of such material,

the pipe; after occupation the signal can be readily put in place again.

The use of the iron pipe for a step is not absolutely essential for this class of signal, as the pole may be set up in earth or sand, or thrust down into a break in rock or coral.

108. Secondary signals, being free from the requirement that they shall be capable of having the exact center occupied, take on a nearly infinite variety of forms. Surveying expeditions are always liberally supplied with sheeting (the coarsest and cheapest qualities answering the purpose) and with lime from which whitewash may be made; with these two aids almost any object can be rendered sufficiently conspicuous to serve as a signal. Examples of such are a whitewashed cairn of stones carrying a pole with sheeting flag; a whitewashed barrel filled with earth or stones surmounted by a flagpole; a conspicuous daub of whitewash on a vertical rocky cliff; or a piece of sheeting with weighted corners suspended from the top of such a cliff. It sometimes occurs that certain features stand out with sufficient clearness to need no further marking by the surveyor, such as a cupola, a chimney, a lone tree, or a rock; but even these will usually be rendered more available by the addition of a flag or some whitewash.

109. In many of the cases where a sheeting flag is suggested for use in connection with signals, its place may be taken by a cage constructed of wooden slats or barrel staves, or by a target made of tin cans or boxes, such as are used for packing oil, hard bread, or paints in the ship's stores. Two targets at right angles formed by strips of sheeting nailed to laths have the advantage of presenting a broad surface from all directions; but being immovable they may sometimes be less easily picked up than a fluttering sheeting flag of smaller area. In the use of sheeting it is a wise precaution to slash every piece with a knife or machete; while not lessening its efficiency for signal purposes this detracts from its value as

and the structures can be quickly erected at any desired point. Their advantages are particularly apparent for tripods and towers of such height as would require the joining of two or more lengths of wooden scantling. Like the wooden structures, when no longer required in the position in which first erected they may be

dress goods and thus contributes to its permanency in an inhabited neighborhood; moreover, by spilling the wind a further advantage of durability is gained.

110. Water signals are those erected on shoals and reefs, and are frequently indispensable for both main and secondary triangulation. The spit or reef which makes out from a point of land is sometimes a better site for a signal than one on the point proper, affording a more extensive view of neighboring coasts; a signal on a detached reef may aid greatly in connecting triangles. Being usually built in shallow water, water signals admit of almost as wide a variety of construction as do shore signals. In water of a depth of 2 feet a tripod signal may be erected, anchored, and occupied almost as easily as on shore. A piece of galvanized iron pipe or a sharpened pole may often be shoved down into mud or soft coral and surmounted by a flag; or a pipe may be forced into a sandy bottom at considerable depth by a stream of water sent through it under pressure. Poles may be supported by piles of stones or by filled barrels or boxes as well under water as on shore.

It need hardly be suggested that low tide is the best time for work in connection with water signals.

111. Permanent marks should be left to indicate the exact position of the more important stations of the survey, so that future work, such as verification of soundings or extension of topography, may be done in the vicinity without the necessity of repeating all parts of the work. A common method of doing this is to place a bottle containing the name of the station and name and date of the survey at a point below the surface so that its vertical axis coincides with that of the station, a surface mark being placed to indicate the locality; the latter in an uninhabited region may be merely a cairn of stones but in a settled neighborhood should be something more substantial, as a pier of concrete or brick. Another good mark is a short length of pipe driven vertically downward and having its

dismantled and the material used for a similar structure in some other part of the field.

head surrounded by a concrete block. The exact location of stations should be accurately described in the records, and their position referred, by distances or angles if possible, to neighboring objects of a conspicuous and enduring nature.

112. Names are assigned to all stations for convenience of reference; these should preferably consist of no more than three or four letters each, and may either be derived from the region in which they are situated, or assigned arbitrarily. Thus, a signal upon Torrecilla Point might be "Tor" or one on some isolated sand spit "Spit," while names of members of the survey party may be assigned by syllables to signals, or an alphabetical sequence given to the names of a series of signals to facilitate memory, as "Ant," "Boy," "Cat," "Dog." Care should be taken, in order to avoid confusion in recording the names of observed stations as they are called out, that points in the same region do not have names of similar sound; thus, if signals on Conch Point and Donato Point are near together, name them "Con" and "Nat" rather than "Con" and "Don." The practice once adopted of assigning letters instead of names to designate signals may be regarded as obsolete.

CHAPTER V.

THE TRIANGULATION, MAIN AND SECONDARY.

113. The main triangulation comprises a series of stations established by angles from one another, originating at the base stations, which mark in outline the complete area of the survey; the object of these stations is to furnish a system of points located with the utmost available accuracy, to which observations in any region may be referred as a whole.

114. The secondary triangulation comprises a series of stations generally intermediate in position to the main triangulation stations and established therefrom; the object of these stations is to afford a basis for detailed observations in any region, and this requires that, from any point in the water area to be surveyed, there shall be visible three signals so situated as to be available for fixing the position by the three-point method.

115. In the survey of an extended coast, it may occur that three systems of triangulation will be distinguished—main, secondary, and tertiary; in this case the main triangulation comprises stations at wide intervals located with a view to carrying forward the extension of the original base, while the secondary and tertiary systems fulfill respectively, for any given region, the parts that would be assigned to the main and secondary in a survey of ordinary extent. Similarly, in the survey of a small area, as a harbor, it sometimes occurs that only one system—the main—is employed.

116. The accuracy of observation of angles varies with the character of the triangulation and the extent of the survey, the greatest care being bestowed upon the measurement of

angles of the main triangulation and of those involving triangles with long sides.

117. The main triangulation is observed with the most accurate available instrument,* and all angles are repeated (art. 29), the measurement being made never less than three times each with telescope direct and reversed. Angles should preferably be measured between each main station and its adjacent one; thus in figure 28, if *O* is occupied, and *A, B, C,* and *D* are other main stations in sight, an occupation would involve the measurement of *AOB, BOC, COD,* and *DOA,* which would afford data for determining the angular distance between any two stations. If one of the stations is less clearly visible than the rest, the plan may be modified by using the same station as origin for measuring two angles, avoiding one sight on the indistinct station; thus, if *C* is not clearly defined, measure *BOC* and *BOD,* which gives the true direction of *D* as referred to *B,* even if the angle *BOC* is in error. The angle *DOA* need not be measured if we may assume that all the other angles are correctly known, since it equals 360°—*AOD;* but it should nevertheless be observed as a check upon the rest, and for the same reason it is customary, in the most accurate surveys, to measure various combinations of angles as a test of their component parts; thus, in the figure, *AOC* would furnish a check for *AOB* and *BOC.* Since it never occurs that flawless observations can be made, it becomes essential to obtain data which will afford a comparison of results; whence, by a process of adjustment, the most probable value of any angle is derived.

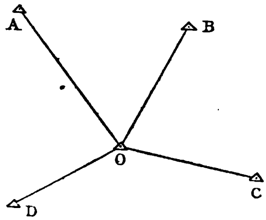


FIG. 28.

* The equipment of a triangulation party is given in Appendix IV.

118. To obtain the most satisfactory results, care and time must be devoted to the main triangulation. If a station is occupied and the conditions of light or weather are unfavorable for the observation of all others visible from it, or if, for any reason, the results obtained are open to doubt, the station should be revisited and other trials made. As a rule, the reflection of the sun's rays will make stations toward the West more clearly visible in the forenoon, and those toward the East in the afternoon. Sometimes the ray of light from another station is refracted in azimuth by the inequality of temperatures to right and left of it, as when land is found on one side and water on the other; if such error is suspected the angles involved should be measured in the early morning, when land and water are more nearly of equal temperature. Judgment and patience are required in the main triangulation to a degree not essential in other parts of the work. The observer should recall that an angular error of 1″ at the distance of one mile produces a linear error of 0.3 inch, and that this error increases in direct ratio with the distance; thus it may be seen that in observing a station several miles distant, an error of a few seconds that might ordinarily be regarded as negligible would have a really material effect.

119. The secondary triangulation need not be observed with the same degree of care as the primary, partly because the lines are shorter, but principally because a given error has only a local effect instead of being caried forward accumulatively. For these reasons it is customary to measure the angles of the secondary triangulation only once—or at most twice, the practice being to set the zero of the theodolite upon a given main station, and measure a round of angles (art. 28), taking in not only all the secondary stations, but also all topographical features, such as peaks, artificial structures, and shoreline tangents which it is desired to locate from the occupied station.

Place: Approaches to Toro Passage.
Date: Feb. 19, 1907.
Station occupied: ▲ Rock.

Observer: H. W.
Recorder: T. J. P.
Instrument: 7-inch theodolite.

No.	Angles.	Objects observed.	Remarks.
	0° 00′ 00″	▲ East.	Angle read 10 times—5 tel. direct and 5 tel. reversed.
1	84 15 30	▲ Tor.	
10	122 34 40		
	720		
	842 34 40		
Final	84 15 28	East. Tor.	
	0 00 00	▲ Tor.	Do.
1	75 12 00	▲ Bat.	
10	32 00 50		
	720		
	752 00 50		
Final	75 12 05	Tor. Bat.	
	0 00 00	▲ East.	Magnetic bearing, S. 42° 12′ W.
	13 15 30	E. tang. Careening Cay.	
	17 28 30	⊙ Wire.	
	30 36 00	S. tang. Puss Pt.	
	30 58 30	⊙ Puss.	
	31 19 00	N. tang. Puss Pt.	
	38 15 30	High peak, summit.	
	2 42 30	Altitude of do.	
	50 11 00	Tang. Long Pt.	Station occupied 7.15 to 9.00 A. M. Fair and pleasant. Light N. W. breeze. Conditions favorable.
	51 18 30	End of breakers off do.	
	83 50 30	N. tang. islet off Toro Pt.	
	83 52 00	S. tang. do.	
	84 10 30	Tang. Toro Pt.	
	161 12 00	Consp. tree near Bat.	
	1 17 00	Altitude of do.	
	345 17 30	E. tang. Careening Cay.	
	360 00 00	▲ East.	

Specimen opening of Angle Book

120. The record of triangulation is kept in a book known as the *angle book,* of which a specimen opening is given on page 83. It should be kept by an assistant to the theodolite observer, the latter calling off the objects observed and the readings and the recorder "calling back" as he writes them down. The average value of repeated angles should be deduced by the recorder as soon as the whole angle is given to him, in order that it may be compared with the first reading and any discrepancy investigated immediately. Full explanatory notes should be entered accompanied by sketches when necessary, the whole being in such form as to be clearly intelligible to any person at any future time.

121. Reduction to the center.—It may sometimes occur that an angle of the main triangulation has to be observed elsewhere than from the center of a station, as when it is not practicable to construct a tripod signal, or when a tripod leg or other object obstructs a particular line of sight. In such case a position is occupied as near the center of the station as possible and the distance from that center measured, as well as the angle between it and one of the stations to be observed; then the correction, called the "reduction to the center" is made by calculation.

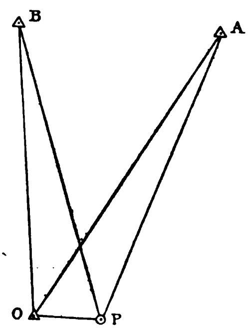
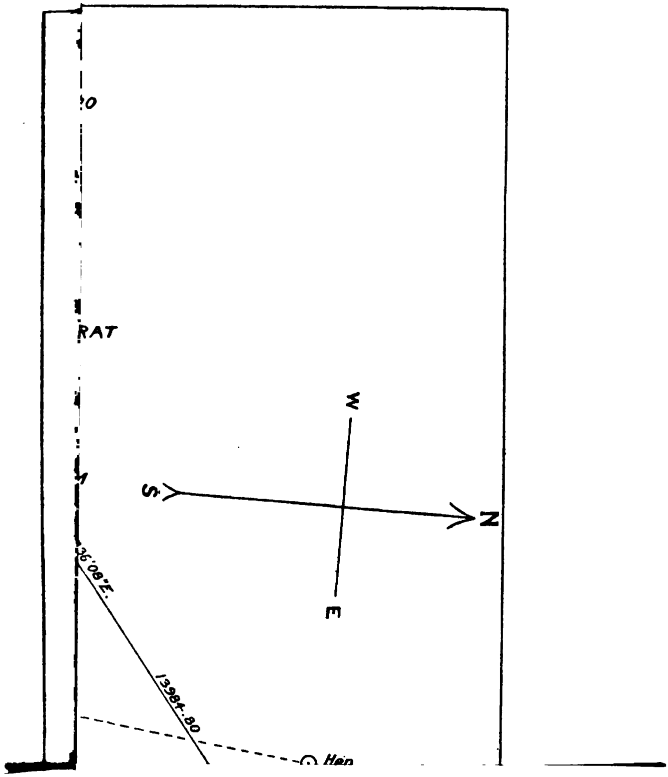


FIG. 29.

In figure 29, let O be the center of the station; A and B, two stations to be observed; and P, the point at which the instrument is set up. Measure the angles APB and BPO and the distance OP; also calculate roughly the distances AO and BO, for which it will be sufficiently accurate to employ the uncorrected angle. Let $AOB = \alpha$; $APB = \alpha'$; $BPO = \theta$; $OP = d$; $OA = a$; and $OB = b$. Then:



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Hen
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E

$$a = a' + \frac{d \sin (a' + \theta)}{a \sin 1''} - \frac{d \sin \theta}{b \sin 1''},$$

the second and third terms of the expression representing seconds of arc. Attention must be paid to the signs of the trigonometric functions.

If the point P is chosen on the line OB we have $\theta = 180°$, and the expression becomes:

$$a = a' - \frac{d \sin a'}{a \sin 1''}.$$

122. Sextant observations have sometimes to be depended upon for triangulation, and are of sufficient accuracy to satisfy approximately the ordinary conditions of a harbor survey; in this case, the best instrument available should be used, and in the main triangulation several measurements of each angle should be made and the mean taken.

Should it occur that the two objects to be observed are at different angles of elevation from the observer the angle measured between them will be an inclined one which will require reduction to the horizontal. This may be done by computation, by measuring, in addition to the angle between the objects, the angular elevation of each, and substituting the appropriate values in the formula for determining the true azimuth by sextant observation of a celestial body. Practically, the necessity for computation may frequently be avoided by selecting a visible point lying vertically below the elevated object and at a proper altitude to permit observation in the horizontal plane, and measuring to this point instead of the real object.

123. Small angles.—It should be kept in mind, in selecting triangulation stations, that a point can not be considered well established when its position depends upon the intersection of two lines making with one another an angle of less than 30° or more than 150°, as in such cases a small error of observation makes an unduly large error in the resulting detemina-

tion, whether arrived at by computation or by graphic plotting, But it should be understood that this restriction applies only to what is known as the *receiving angle*—that is, the angle at the point which is to be established—regardless of any other angles of the triangle; thus, in figure 30, if *B* and *C* are two stations which are well established, a station *A* may be perfectly well determined from them, since its receiving angle is of favorable size; for as far as that station is concerned the position depends upon the relative directions of the lines *BA* and *CA*, and it is immaterial whether the triangle be *ACB*, which has a small angle at *B*, or *ACB′*, which has a large angle at *B′*.

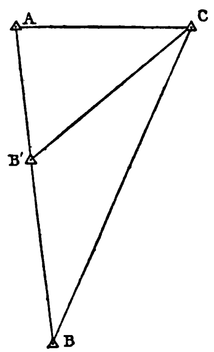


FIG. 30.

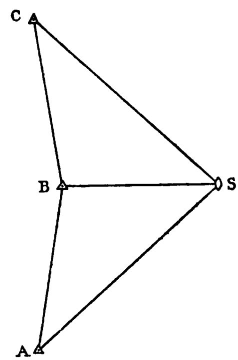


FIG. 31.

124. Coast-line triangulation.—In carrying forward triangulation along a coast-line, it becomes necessary to find suitable stations either inland or to seaward which will permit the formation of the necessary triangles, as shore signals will lie too nearly in a straight line to afford the proper intersections. A solution of this difficulty is sometimes found in a chain of offlying islands upon which stations may be located; or, where there are no islands, signals may be built upon conspicuous heights lying well back from the coast.

Where neither of these methods is available the object may be accomplished by using the ship as a temporary signal, though this lacks the nicety of regular methods. In figure 31, let *A* and *B* be two stations of known position, and *C* a station whose location is to be determined; an observer with a theodolite stationed at *B* sets up his instrument with zero on *C;* the ship proceeds to *S* and stops or anchors, making the triangles *ABS* and *BCS,* as nearly equilateral as the position of stations will admit; in a conspicuous position, as on the fore stay, the ship hoists a shape that will appear as a definite mark for observation by the theodolite, and vertically beneath it (or as nearly so as possible) two observers are stationed with sextants; a signal having been made as previously agreed upon, simultaneous observations are made, the sextant observers measuring, respectively, the angles *ASB* and *BSC,* and the theodolite observer measuring *CBS* and then, having read the limb, swinging the telescope to *A* and measuring *SBA;* data will now be at hand for the location of *C* either by graphic methods or by computation; several repetitions of the observations are made from either the same or a different position of the ship. When time admits and the most accurate results are sought, observers with theodolites may also be stationed at *A* and *C* to measure *BAS* and *BCS,* in which case the sextant angles may either be dispensed with or assigned only a minor weight in the adjustment. The station *C* having now been fixed in position, either *BC* or *AC* is available as a base for fixing the next station; and so the triangulation may be continued from one point to another along the coast. This same principle may also be employed upon a smaller scale, substituting a boat for the ship.

125. A diagram of triangulation illustrating the arrangement of main and secondary stations in a hydrographic survey is given in Plate I. A study of this will give a clear idea

of the objects to be sought in choice of stations; particular attention should be paid to the system of quadrilaterals upon which the main line of the triangulation is extended; the advantages of the quadrilateral over the simple triangle as a basis of computation will be explained later (art. 218).

CHAPTER VI.

TOPOGRAPHY.

126. The topographical work of a survey comprises the delineation of all requisite features of the land, including the shore-lines of mainland and islands, all artificial and natural features, and, generally, all things on land a knowledge of whose position may be of value to the navigator, especially as aids in fixing his ship's position.

127. This work divides itself into three general classes:

(*a*) The delineation of prominent features, such as lighthouses, peaks, and other conspicuous landmarks, which are visible from two or more established stations of the survey and can therefore be located by observations of the same nature as those employed for locating secondary triangulation stations;

(*b*) The delineation of the shore-line, which is an essential part of every survey, and which can be properly done only by an observer passing along the shore and locating a series of positions thereon;

(*c*) The delineation of special features, such as lines of equal elevation, courses of streams, and character of ground, which is completely carried out only in the most thorough surveys, and involves the taking of observations at close intervals throughout the whole region covered.

128. Triangulation method.—The observations for the establishment of prominent points in the topography by direction-lines from main triangulation stations has been referred to in connection with the secondary triangulation (art. 119) and the method needs no further explanation. It may, how-

ever, be added that, in so far as it is applicable, this is the quickest and most accurate of all topographical methods, and time is well spent, after the measurement of the angles of the main triangulation at any station, in "cutting in" every object of any prominence and every tangent to a shore-line which may be recognized; even if no second cut is secured from another direction the single line is frequently of much value.

129. Elevations and depressions.—Incidentally, this observation affords a method for obtaining the altitude of peaks and other prominent objects in relation to that of the occupied station which should always be taken advantage of; for while it is only occasionally that the surveyor has an opportunity to determine a complete system of contour lines by a leveling instrument, and such lines are of minor value to the navigator, the altitude of the more conspicuous points is an essential to a good navigating chart.

The observation consists in measuring the angle of elevation (or depression) of the point whose height is required above (or below) the horizontal of the occupied station; this measurement is preferably made with a theodolite having a vertical circle, but a sextant and artificial horizon may be substituted. In figure 32, let A be the occupied point, and B, an observed point at a greater elevation; AM, the tangent at A to the refracted ray of light between A and B (the latter shown dotted); AH, the true horizontal of A, cutting the vertical line through B at a height $B'H$ above the earth's surface; O, the center of the earth; and D, the angle in minutes subtended by AB, equal to the horizontal distance between those points in nautical miles, as given by the results of the survey.

It has been found that the effect of refraction is such that the observed angle, MAH, will, under normal atmospheric conditions, be greater than the true angle of elevation, BAH, by an amount equal to one-thirteenth of the angular distance,

D. Remembering this, and regarding BHA as a right angle, we have:

$$BAH = MAH - \tfrac{1}{18}D;$$
$$BH = D \tan BAH;$$
$$BB' = BH + B'H.$$

In the first equation, D is taken in minutes of arc, these being equivalent to nautical miles; in the second, in feet.

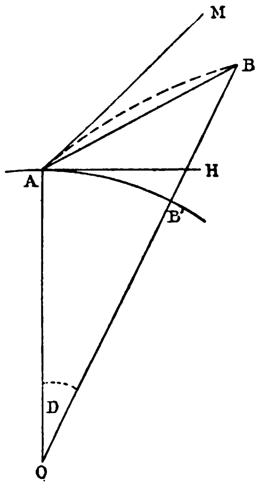


FIG. 32.

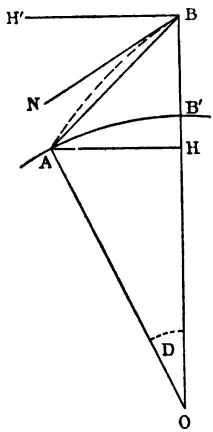


FIG. 33.

The height, $B'H$, called the "dip" (though not to be confused with the angle so termed in navigation), is tabulated in Appendix II, or may be computed by the formula:

$$\text{Dip} = .8815 \times D^2;$$

wherein D is expressed in nautical miles, the resulting dip being given in feet. This expression may be deduced from a consideration of figure 32, in which:

$$(OH)^2 = (OA)^2 + (AH)^2;$$

or, calling the dip p and the radius of the earth r,

$$(p+r)^2 = r^2 + D^2;$$

$$\text{hence, } p^2 + 2pr = D^2;$$

and, neglecting p^2, the value of which is inconsiderable,

$$p = \frac{D^2}{2r};$$

substituting in which the value of the mean radius of the earth and reducing to feet, we have:

$$p = .8815 \times D^2.$$

Figure 33 illustrates the case of the observation being made from the more elevated station, B, to a lower station A. The observed tangent to the ray is BN; the true horizontal at B is BH'; and AH is a line through A parallel to the observer's horizon, cutting the vertical line through B at a distance $B'H$ below the earth's surface; otherwise, the lettering conforms with that of figure 32. In this case:

$$BAH = H'BA = H'BN + \tfrac{1}{13}D;$$

$$BH = D \tan BAH;$$

$$BB' = BH - B'H.$$

The value of $B'H$ may be found from the table or by computation from the same formula as in the preceding case, the process of the deduction of the formula differing in detail but leading eventually to the same result.

While A has for illustration been assumed as at the earth's surface, it is clear that the deduced difference of altitude holds good for any other position of the less elevated station; also that whether the occupied or the observed station is of known altitude, the true height of the other may be found. The height of the instrument above ground should be subtracted from that of the occupied station. The records should show whether an observed elevation refers to the ground or to the

top of the foliage at any station. The surveyor must not overlook the necessity for locating the exact point observed, preferably by a cut from a second station, not only for correctly plotting on the chart the point whose altitude has been determined, but also for obtaining the value of D for use in the computation.

Elevations are usually referred to the plane of mean high water. The adopted plane of reference should be stated in the legend of the chart.

130. Shore-line observations cover a wide variety of methods, of which the one best adapted to existing conditions must be chosen.

131. The *plane table* in conjunction with the telemeter affords a most satisfactory means of conducting the work, though only available when the shore-line admits of being followed on foot—a condition more rare in unsurveyed regions than is generally realized. The table is set up at some point of established position, and a traverse is made from there as an origin; each successive position of the plane table, designated by a number or letter, is established by telemeter distance from the one before and further checked by resection angles at the point occupied; and at each occupied position all important topographical features are cut in and tangents observed wherever possible; stretches of shore-line between determined points are sketched in by the eye, and full notes made. A specimen of a plane table sheet made by this method is shown in figure 34.

132. When greater accuracy is required, a *transit* may be substituted for the plane table, and a *chain* or *tape* for the stadia measure of distance. Set the theodolite up at some determined point from which the line is to begin, as at the station "Hat" (fig. 35); clamp the upper plate with the scale reading zero and direct the telescope toward some determined

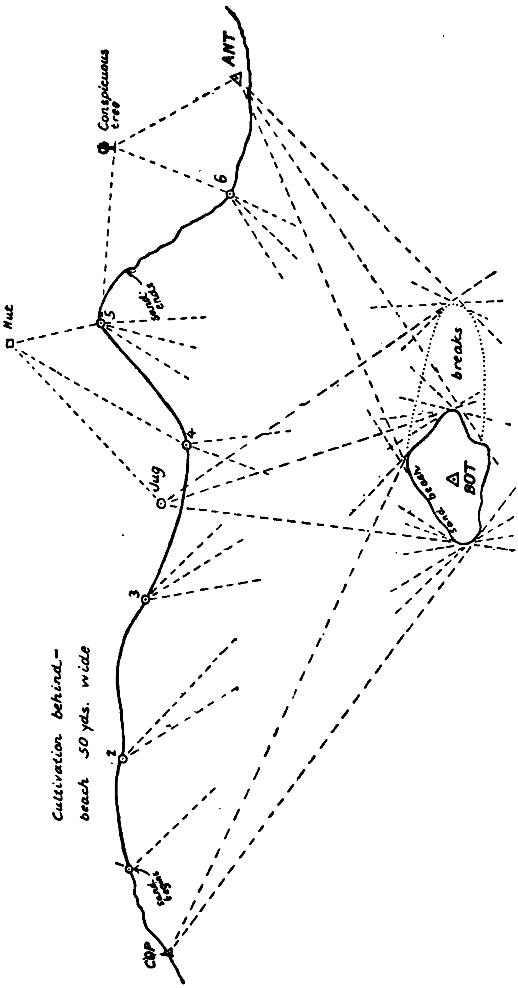

ANT
Conspicuous tree
6
Hut
5
sand ends
breaks
4
Jug
BOT
sand beach
3
Cultivation behind beach 50 yds. wide
2
sand begins
COP

FIG. 34.

station, as "West"; clamp the lower plate. Send an assistant with a pole or flag to mark the point chosen for the end of the first line to be measured—Station 1—such point to be at the greatest distance that permits of uninterrupted measure in the prevailing direction of the shore-line in this vicinity. Unclamp the upper plate and bisect the mark at the new station; then clamp the upper plate. By chain or tape measure the distance to Station 1, following the methods as described for base-line measurement, aligning the fleets by the telescope; at such intervals as may be required measure offsets at right angles, both to the water's edge and to such points in-

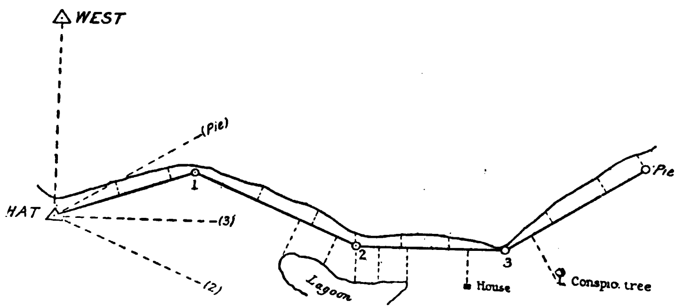


FIG. 35.

shore as need to be located, keeping careful note of the amount of such offsets as well as of the distance from the origin of the line at which they are measured. Follow carefully the instructions hitherto given for keeping tally of the number of fleets of chain or tape. Station 1 having been reached by the measuring-party, its position is temporarily marked, and the transit, still clamped, is brought up and erected thereon, while the assistant is sent ahead to mark Station 2; now transit the telescope, unclamp the lower plate, and bisect the station left ("Hat"), and again clamp the lower plate; transit the telescope once more so that it points along a prolongation of the

line Hat-1; then unclamp the upper plate, swing the telescope to bisect Station 2, and clamp again. The telescope now points in the direction 1-2, and its scale indicates the angle between this direction and that of the line Hat-West. Measure this line with its offsets as before, and continue from point to point successively in the same manner, following the rule, at each change of station of the instrument, of transiting, unclamping the lower plate and sighting back to the last station, clamping, transiting, unclamping upper plate, sighting on the new station, and clamping again; by this method is maintained what is designated the "constant zero"—that is, all directions are referred to the one originally established (Hat-West, in the case illustrated). In plotting shore-line thus observed, all angles are laid off from the station first occupied (as Hat-1, Hat-2, ..., Hat-Pie); then the distance to Station 1 having been laid off on its appropriate line, the position of the latter is determined; through this point the direction 1-2 is laid down parallel to Hat-2, and the position of Station 2 established by its distance; and so on. Offsets are laid down at their proper intervals and their extremities connected by sketching. The last line should end at a determined station, which affords a check upon the work. Discrepancies may be readily reconciled by this method, and may be attributed entirely to errors in measures of distance and treated accordingly, since the probability is less in favor of an error in angular measure.

A modification of the foregoing which contributes to simplicity at small expense of accuracy is to employ the magnetic needle for establishing direction instead of angular measure.

The records for this method are usually kept in graphic form.

133. In a further extension of the same method which yields less precise results, the transit is replaced by a *surveyor's compass,* or even by a navigating compass mounted upon a tripod,

and the telemeter by sextant angle of a pole of known length (art. 49). This plan may be utilized, for example, where the shore-line is mangrove and can not be walked over but may be skirted in small boats; an observer with compass and sextant goes in one boat (which should be free from magnetic material that would cause local deviation of the compass), while an assistant with the pole goes in another boat; a regular traverse is made precisely as on foot, the boats holding themselves in position during observation by means of the foliage or a pole driven down into the bottom; in making shifts of position, the rear boat may come up and assume the place of the front one, the latter then moving forward, or, what is usually more convenient, the rear boat at any position may pass ahead of the other and become the front one, taking up the next station and establishing its place by sighting back to the last position.

134. An expeditious and satisfactory method of determining shore-line is to let an observer pass along the shore, on foot or by boat, with a sextant, and make frequent determination of position by the *three-point method* (art. 142). Where signals are favorably situated for the purpose and the observer can avoid "revolvers," or indeterminate cases, this plan has much to recommend it; but it will frequently be found that the available signals will not prove as numerous as expected, for the reason that projecting points and foliage will shut out, to an observer on the shore, signals visible throughout the neighboring water area.

135. Where a stretch of shore-line is visible from two stations of determined position, an observer with a theodolite or transit may be placed at each of the stations while a third passes along the shore on foot or by boat, pausing from time to time to make a signal—as the hauling-down of a wigwag flag—upon which each station observes a direction-line with reference to some fixed line of the survey, and thus cuts in

the position by *triangulation methods;* in this and similar cases each of the three observers must keep a record of the time of each observation by compared watches, in order to locate any "lost" observations.

136. A *combination of the two preceding methods* may be employed, necessitating two observers, one at a determined station and one upon the shore-line. The former cuts in the successive positions on the shore-line upon the hauling-down of the flag, while the latter observes the angle between two stations—one of which, for convenience, should preferably be that occupied by the theodolite—the method of plotting being as described for a similar case in hydrographic work (art. 147).

137. Finally, a method of occasional value is shown in figure 36, wherein the observer on the shore-line *can see only one triangulation station* at a time, but a boat at a short distance out has several stations in sight. Let the boat take position at D, moor head and stern so as to be held as nearly as possible immovable, and fix position by observation of the three points A, B, and C, thus becoming an auxiliary station; then at any point, X, upon signal, the boat observer measures by sextant the angle ADX, while the shore observer measures AXD, whence the position X may be plotted.

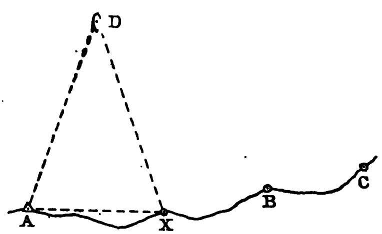


FIG. 36.

138. Complete topographical observations involve a traversing of the whole land area, fixing position at frequent intervals and noting the altitude and characteristics of the ground at each position. The methods just described for the delineation of shore-line are equally available for this class of topo-

graphical work. The streets of a town, the course of a stream, or the limits of ground of any given character, as forest or cultivation, can thus be comparatively quickly run in.

139. Elevation contour-lines, being a series of lines of which each includes all points at the elevation which it represents, are required upon charts complete in topography. They may be determined in either of two ways.

In the first, the observer establishes himself at the height of one of the required contour lines, determines his position, and sets up a Y-level; the height of the horizontal cross-wire above ground is then measured, and the target of the leveling-rod set at that height; the assistant with the rod then proceeds to various localities, moving up or down hill at each under the direction of the observer until the target is bisected, when the position of the rod is determined; for most purposes, the Y-level may be replaced by the plane table with telescope set horizontal, which will greatly facilitate locating the various positions. This method is not often employed in connection with a hydrographic survey.

In the second method, the altitude and position are determined for a large number of points at different heights, and the elevation contour-lines sketched accordingly.

In both methods, care must be taken to make correction for "dip" and refraction (art. 129) if any two stations are separated by a material distance. Where precise results are not sought, a hand level may be substituted for the Y-level or equivalent telescopic instrument; or, in such case, the aneroid barometer gives sufficiently accurate results for the ordinary hydrographic chart, affording the most expeditious means of developing contours, as its results do not depend upon those at other stations, and the observer has merely to proceed from point to point fixing his position and recording the height.

CHAPTER VII.

HYDROGRAPHY.

140. Soundings are made either from the ship or a boat—the former generally being employed for offshore, and the latter for inshore work; in either case, the general principles governing the fixing and plotting of position are the same. In what follows, the case of sounding from the boat will usually be referred to for illustration, this being more frequent in practice, and such modifications as may be required in ship work will readily suggest themselves.

141. Methods of fixing position.—There are three methods available for locating the position of a ship or boat from which soundings are taken, while in the vicinity of triangulation stations (main or secondary) of established position:

(*a*) By the simultaneous observation of the angles between the right and left pairs of three stations, known as the *three-point* observation;

(*b*) By the observation, from the ship or boat, of the angle between two stations, and simultaneously from an established station on shore, of the angle between the ship or boat and some other station; and

(*c*) By the simultaneous observations from each of two stations on shore of the angle between the ship or boat and some other station.

The methods of fixing position by compass bearings, so generally employed in navigation, are deemed of inferior value in surveying; they are occasionally employed in ship work, where only two signals are visible and the ship's compass has an accurately determined deviation; they are not, however, available for boat work.

142. The three-point method is so generally employed in surveying for fixing position under way that other methods may be regarded as exceptional, being used only under special circumstances. This method involves the solution (in practice always accomplished graphically) of the *three-point problem,* which may be stated as follows: Required to find a point such that lines drawn from it to each of three given points shall make given angles with one another.

The observation consists in the selection of three established stations marked by visible signals, and the simultaneous measurement by two observers with sextants of the angle between the middle station and each of the others.

143. The method of plotting position from such observations has been described (art. 60). It may, however, be remarked in this connection that facility in plotting is acquired only with practice, the novice usually wasting much time in trying to move the protractor in a haphazard way until the three arms chance to fall simultaneously upon their respective points; a systematic method which will save such groping consists in placing two of the arms—preferably the two outer ones—upon their proper points, and then sliding the instrument, always in such a way that these arms continue to bisect the points, until the third arm comes into proper position.

144. A discussion of the three-point problem in its mathematical bearings is assumed to be needless; it may simply be pointed out that from one of the measured angles—the right one, for example—it becomes known that the observer's position lies upon the circumference of a circle which passes through the right and middle stations and from every point of which those stations subtend the observed right-hand angle; similarly, it is known that the position is on another circumference which passes through the left and middle stations and from every point of which those stations subtend the observed left-hand angle; and finally, that the observer's position can

only be at the intersection of those two circumferences. It follows that when the stations are so chosen that the two circumferences intersect at right angles, or nearly so, the determination will be accurate and the inevitable small errors of observation and plotting will have a relatively slight effect upon the resulting "fix"; if, on the contrary, the two circumferences approach coincidence with one another and consequently intersect at small angles, slight errors will make a much greater difference in the result; and if the two circumferences coincide completely, as is the case where the circle through the three observed stations passes also through the position of the observer, there being no single point of intersection, the problem becomes indeterminate; in this latter case, as an attempt at graphic plotting will reveal the fact that the center of the protractor may be made to follow around the whole circumference, its arms at all times passing through the respective stations, this condition is known as a *revolver*. The conditions of a favorable, an unfavorable, and an indeterminate observation are shown respectively in figures 37, 38, and 39, in each of which *A, B,* and *C* represent the observed stations, and *P* the position of the observer.

145. A method by which the conditions of a revolver may be avoided is to picture in the eye a circle drawn through the three stations selected for observation and to note whether it passes near the position of the observer; if it does, one or more of the stations should be rejected in favor of another or others.

146. The following thumb-rules describe the conditions which will result in an accurate determination:

(*a*) When the middle object of the three lies between the observer and a line joining the other two;

(*b*) When the sum of the right and left angles is equal to or greater than 180°, showing that the observer is on one of the sides of the triangle joining the objects or is within that triangle;

(*c*) When two of the objects are in range while the angle to the third is at least 30°; and

(*d*) When the three objects are in the same straight line.

With the single exception that occurs when two of the objects are in range, objects should, if possible, be so chosen as to give angles of not less than 30°. Other things being equal,

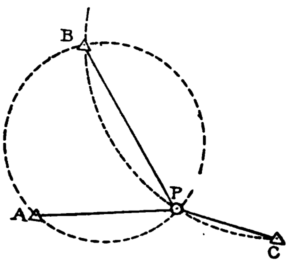


FIG. 37.

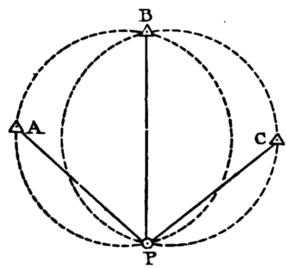


FIG. 38.

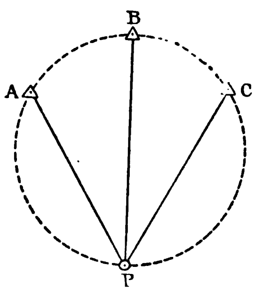


FIG. 39.

preference should be given to near, rather than to distant objects; but the conditions are always less favorable when one of the three objects is very close as compared with the other two. It should be remembered that the fact that objects are so located as to give a favorable fix by the method of magnetic cross-bearings does not insure their availability for the three-point observation.

147. Observations from boat and shore.—This method of fixing position, together with the one which follows, lacks that advantage possessed by the three-point method which permits the immediate plotting of position as soon as the observation is made; the ability to run lines of sounding in exact accordance with a projected plan is thus sacrificed. The methods are, nevertheless, of occasional use, as, in inshore work, in a pocket or bight whose importance does not justify the erection of a sufficient number of signals to make the three-point method available, or, in offshore work, where the ship affords a more clearly visible mark than the signals which have been erected.

In this method an observer on the boat or ship is prepared to measure the sextant angle between two visible triangulation stations, while one ashore occupies with a theodolite a station of determined position, adjusts the zero of the instrument upon some triangulation station, and holds himself in readiness to measure the angle of the boat or ship at any instant from the zero station. Simultaneous observations are made at times indicated by a prearranged signal; the record in each case includes a note of the time, taken by compared watches, in order that any lost observations may be located.

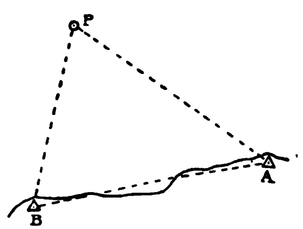


FIG. 40.

The plotting is much simplified if the station occupied by the observer is one of those observed from afloat. To illustrate this case, let A (fig. 40) be the occupied station; B, another triangulation station; and P, the position of the boat or ship; suppose that the shore observer has measured the angle BAP, and the observer afloat the angle APB; with the protractor lay off from A the direction-line AP, making the required angle with AB; then

set the protractor for the angle *APB*, and, keeping the edge of its left arm always coincident with *AP*, move it in or out until the right arm passes through *B*, when prick the point *P*.

Figure 41 represents the case where the occupied station is not one of those observed, *A* being the position of the shore observer, who measures the angle *BAP*, and *P* that of the boat or ship, from which the angle *BPC* is measured; lay off the direction-line *AP*, as before, and set the protractor for the angle *BPC*; now, keeping the two arms of the protractor always bisecting *B* and *C*, slide the instrument over the sheet until its center is seen to cross the line *AP*, at which point prick the position *P*.

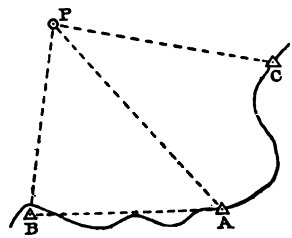


FIG. 41.

148. Two observations from shore.—This method, which, like the preceding, is open to the objection that positions can not be plotted while sounding is in progress, involves the employment of two observers at stations on shore, each of whom, upon signal from the boat or ship, observes the angular distance thereof from some determined line of the survey. As in similar cases, a record of times is kept by compared watches.

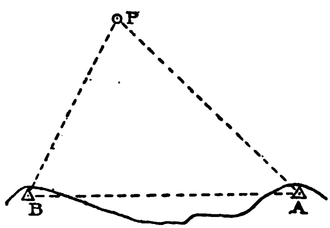


FIG. 42.

The details of observation and plotting suggest themselves, being equivalent to those of triangulation; in figure 42, let *A* and *B* be stations of determined position occupied by observers; at any position of the boat or ship, *P*, at which a signal may be made the angles *PAB* and *PBA* are measured by the respective observers; when plotted on the sheet, the point of their intersection, *P*, is the required point.

149. Equipment for boat work.—By far the most satisfactory boat for sounding is a launch propelled by steam or other power; despite the excellent results achieved in earlier days in boats under oars and sail, the launch of modern times is, when available, the only craft now to be considered for such employment.

150. The fittings for sounding are such as may be readily supplied to an ordinary service launch. The boat should be provided with a canopy to keep off sun, rain, and spray; a couple of battens across the stern sheets forming a rack upon which the board carrying the boat sheet may be placed; a small leadsman's platform on each side forward (if the survey is not extensive enough to warrant this, leadsmen's slings and aprons will suffice); an anchor and cable, the former stowed snugly as far from the compass as convenient; three lead lines (one being spare) carefully tested while wet and under the conditions of stretch to be encountered in use, and marked in feet up to 6 fathoms; and a ship's compass—preferably a 7½-inch liquid compass—secured in place near the helmsman. If the nature of the sounding promises to require it, there should also be slings for the observers, attached to the canopy-frame or elsewhere, to permit sextant work in a seaway: a boat sounding machine, for depths beyond the hand lead; and a patent log, if the fixing of position by signals will not always be feasible. There should always be at hand in a sounding boat a small buoy of a sort readily improvised, with anchor and line attached, which may be quickly tossed overboard to mark the position of a shoal sounding unexpectedly obtained; the mark which such a buoy affords often saves much fruitless searching.

151. The officers and crew ordinarily consist of two observers (officers, the senior in charge of the boat), one recorder (a junior officer or intelligent yeoman), one coxswain, three seamen (employed, two at a time, as leadsmen), and one or two

men (according to necessity) for running the engine; where the soundings are to be made in considerable depths, a fourth seaman should be detailed for sounding work. A list of instruments and other articles to be provided is given in Appendix V.

152. Routine of boat work.—Soundings are run in continuous lines and the principle to be followed in so doing is to fix the position of the boat by observation at the beginning and end of each line and at frequent intermediate points, including any at which a change of course may be made to make the lines conform more closely to the adopted scheme for covering the area under investigation. Since soundings are made more frequently than observations for position, it is essential that a means be provided for plotting the soundings with relation to the fixed positions; this is done by making the speed of the boat uniform, and by taking the soundings which do not coincide in time with observations for position at equal intervals of time between such observations, whence they may be assumed to lie at equal intervals of distance between the plotted positions.

The intervals of time between observed positions (the latter being called simply *positions*) and between soundings are prescribed by the officer in charge of the boat and vary with the depth. Let it be assumed that soundings are to be taken every half minute and positions every three minutes—a common arrangement for inshore work. The officer having gotten the boat into position for the beginning of the line, and the boat being on the prescribed course and at prescribed speed, the first position is taken, and simultaneously a sounding is made—all at the word from the recorder, who notes the time; at half-minute intervals thereafter the recorder gives the word to sound, and soundings are taken alternately by the starboard and port leadsmen, until the sixth such interval, when, in addition to a sounding, another position is observed, and the

process is repeated. If, after plotting the observations, which he does as promptly as possible, the officer in charge finds the boat not making good the desired course, a change is ordered; if the change is of only slight amount—one or two degrees—there will usually be no appreciable error in directing the helmsman accordingly and disregarding the small break thus made between positions; but if it is a change of material amount it should either not be put into effect until the next regular observation for position, or else an extra position should be observed. On reaching the end of a line that runs toward shore, it will seldom occur that the boat will reach the limit of its course on an even three-minute interval, and an extra position must therefore be taken at the moment of the last practicable sounding.

153. To go somewhat more into detail as to the process: The senior officer directs the course, speed, frequency of sounding, and the stations to be observed for each position; he habitually takes the right-hand angle, calls off his observation first to the recorder, and then proceeds to plot the position on the boat sheet, numbering it to accord with the records. The junior observer takes the left-hand angle, calls off his angle to the recorder after the senior's angle has been written down, overlooks and checks the recorder, and supervises the helmsman and leadsmen while the senior is occupied with plotting. The recorder, whose duties at first seem hopelessly complicated to a novice but soon become simple with practice, must keep complete the various columns of the sounding-book, and at the same time give notice of the proper time for sounding and observing position. A usual practice is to allow ten seconds for the leadsman to get an up-and-down cast after the order to sound has been given, and the same length of time for the sextant observers to prepare to read an angle for position; hence, with the intervals that we have previously assumed, a line having been begun on an even minute, the recorder calls

"sound" at 20^s, 50^s, $1^m\ 20^s$, etc., thereafter, until $2^m\ 50^s$ have elapsed; at this interval he calls "position next," whereupon the leadsman begins his cast and the observers stand by; at $3^m\ 00^s$, he calls "mark," at which time the observers read the sextants and the leadsman has his sounding.

154. The record consists in making all required entries in the sounding book, a specimen opening of which is given on pages 110 and 111. The series of numbers assigned to positions is begun anew each day and for each boat. To avoid confusion of such numbers, each day upon which sounding is done is assigned a "daymark," being a letter or combination of letters by which the results of that day are distinguished; thus position "B-42" is the forty-second position on day B. When more than one boat is employed in sounding on any day, the work of each is plotted with ink of a distinctive color; thus, there may be two positions marked "B-42," one in green and one in red, the color showing to which boat's work the position belongs.

The recorder's timepiece must accord with that used in the tidal observations, in order to permit the subsequent reduction of soundings to the standard tidal plane.

Positions are indicated in the records by a check-mark, placed below the number; thus, $\overset{3}{\checkmark}$, indicating "Position No. 3."

Depths are recorded in fathoms and feet and, in surveying, should be so called out by the leadsman, ship traditions to the contrary notwithstanding; thus five and a half fathoms is "five-three"—never "and a half five." Unless varying rapidly, bottom characteristics need only be recorded abreast the soundings made at positions.

The course by compass is recorded in boat work, but since the deviation is always large and undetermined the compass course is of value for comparative rather than for absolute indications.

Place. Approaches to Toro Passage.
Date: Feb. 25, 1907. Vessel: 1st steamer.

Time.	Reading of patent log.	Distance interval.	No. of pos.	Soundings. Original. Fathoms.	Foct.	Red for tide.	Soundings. Reduced. Fathoms.	Feet.	Bottom.	Compass course.
A. M.						ft.				
9.01	......	..	11 V	4	..	—1	3	5	Co.	North.
1½		..	..	4	1		4	..		
2		..	..	4	3		4	2		
2½		..	..	4	5		4	4		
3		..	..	5	1		5	..		
3½		..	..	5	3		5	2		
9.04		..	12 V	6	..		5	5	gy.S.Co.	......
4½		..	..	6	2		6	1	....	N. 2° E.
5		..	..	6	4		6	3		
5½		..	..	7	..		6	5		
6	Not in use	..	..	7	3		7	2		
6½		..	..	7	5		7	4		
9.07		..	13 V	8	1	—2	7	5	gy.S.Co.	..
8		..	..	8	2		8	..	....	N. 5° E.
9		..	..	9	..		8	4		
9.10		..	14 V	10	2		10	..	gy. S.	......
11½		..	..	11	..		10	4	....	N. 4° E.
9.13		..	15 V	12	1		11	5	M	.....
14½		..	..	13	..		12	4		
9.16		..	16 V	15	3		15	1	M	.....
9.20		..	17 V	15	4		15	2	M	S. 12° W.
21½	......	..	..	14	4		14	2		

Specimen opening

Observers: W. J. P., right; E. C. S., left.
Recorder: L. M. S
Leadsmen: E. C. T., J. W., and J. J. C. Daymark: W.

ANGLES.					Remarks.
By whom.	°	′ ″	Right object.	Left object.	
....	56	35	East.	Rock.	Line begins about 50 ft. from
	90	48	....	Bat.	reef and 250 ft. from shore.
....	54	13	East.	Rock.	Islet off Toro Pt. in range with
	78	52	....	Bat.	Cow.
....	50	02	East.	Rock.	Changed sounding interval.
	61	13	....	Bat.	
....	47	50	East.	Rock.	Increased speed and changed
	90	36	....	Pit.	sounding interval.
....	88	27	Tor.	Rock.	
	91	00	....	Pit.	
....	84	32	Tor.	Rock.	Line ends.
	93	11	....	Pit.	
....	87	12	Tor.	Rock.	Line begins. Heading for Rock
	89	37	....	Pit.	in range with hut.

of Sounding Book.

In recording angles of the three-point observation, the right-hand one is called off and written first and the left-hand one afterward; similarly, the right object of the two forming an angle is called off and written first and followed by the left; and the middle object of the three being common to both angles, need be named and written but once; thus, with Ant, Boy, and Cat as the right, middle, and left objects, respectively, of a three-point observation, the record would be made as follows:

Ant-Boy, 85° 16′;
-Cat, 37 42.

And in naming the objects observed a person would have simply to say "Ant-Boy-Cat," and their relative position would be understood without further explanation.

In the column of "Remarks" is written any information of value that does not appear elsewhere. As a check in plotting, note is made abreast any position that begins or ends a line, and if near shore, breakers, an island, or shoal, the fact should be recorded with the estimated distance therefrom; a change of speed, which should only be made at a position, is also here noted. At the beginning and end of each day's work it is customary to record the fact that sextants and lead lines have been tested and found correct.

155. Boat sheets are usually made upon brown or tinted paper to avoid the glare in the eyes that is experienced in sunlight from white paper. They are mounted upon a drawing board in a convenient form for use in the boat; if thumb-tacks are used the paper should overlap the edges and be secured at the sides so that the tacks will not obstruct the movements of the protractor on top of the board. These sheets should show all triangulation signals, and should have a compass rose and scale of distance. Topographical and other features may be omitted, though it is sometimes worth while to sketch them in

roughly as an aid to the eye. The lines which it is projected to run should be drawn in pencil for the guidance of the officer in charge.

The boat sheet is primarily intended for indicating the course traversed by the boat; accordingly, positions are plotted, numbered, and joined consecutively by lines, to show what ground has been passed over; but no attempt is made to record the determined depths thereon. Aside from its value in enabling an officer to run lines in accordance with a precise plan, the fact of his plotting as he goes enables him to detect and locate any error of observation or record in a way not possible for a person plotting from notes at some later time.

As soon as practicable after the completion of each day's work, the boat sheet should be gone over by the officers who made the observations, doubtful positions replotted or rejected, and the whole inked over in the proper color so as to render it a permanent record. If the boat sheet has been made upon the same scale as the plotting sheet of the survey, the positions may be readily transferred from the former to the latter by tracing linen; but the facility offered by this method must not lead to a neglect of the requirement that the boat sheet must be on a large scale to permit accurate plotting.

156. Plan of soundings.—The number of soundings varies with the depth of water, more being made in a given area in shallow than in deep water; but no fixed rule exists, as much will depend upon the time available for the survey, the character of bottom, and the draft of vessels expected to traverse the area; for example, in a harbor navigated by large and valuable ships, especially one where the existence of sharp pinnacles might be suspected, no survey by the lead alone could be considered sufficient, and recourse should be had to dragging or sweeping as a final safeguard.

The main series of lines should always be run in a direction normal to the general trend of coast, and the following may

be considered as a fair interval between lines, where there is no reason to suspect unevenness of the bottom:

Depths to 5 fathoms, 300 feet;
thence to 10 fathoms, 600 feet;
thence to 20 fathoms, $\frac{1}{4}$ mile;
thence to 50 fathoms, $\frac{1}{2}$ mile;
thence to 100 fathoms, 1 mile.

In addition to the normal lines, a second series should be run at similar intervals in a direction at right angles to the first (i. e., parallel with the coast) in depths up to 10 fathoms; and when exceptional care is required other series of lines may be

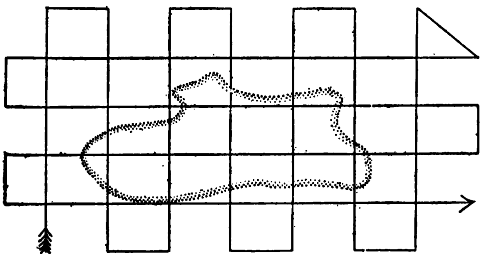


FIG. 43.

run in directions diagonal to the first two. Soundings upon any line should be taken at distances apart not greater than the interval between lines for the existing depth. It is apparent that the sounding obtained on a line of one series should agree with that obtained on a line of another series at the point of intersection of the lines, both soundings being reduced to the same tidal level; this fact offers a means for verifying the accuracy of the work.

157. Developing shoals.—Special lines must be run to develop shoals and reefs, as well as areas where such may be suspected, as, for example, where depths decrease in proceeding offshore. The development may be made either by closely-spaced perpendicular lines, as in figure 43, or by expanding

rectangles, as in figure 44, the boat being run slowly in both cases and soundings taken at frequent intervals. In the case of a submerged shoal dangerous for deep vessels but capable of being passed over by those of lesser draft, the utmost care must be taken to determine the least depth upon any part; it must not be assumed that this corresponds with the least sounding obtained in running lines across it, for it is quite probable that the shoalest spot may be passed over between casts; therefore, when the general development has been completed, the boat should be allowed to drift across the shoal with wind or tide, or be driven slowly across with only an occasional turn of the engines, "feeling" the bottom continuously

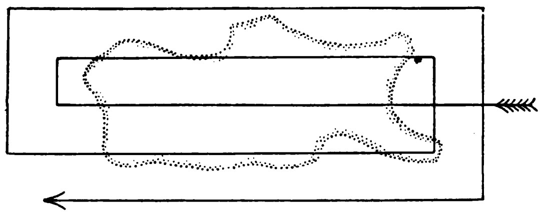


FIG. 44.

with the leads, and this operation should be repeated over all parts; at the shoalest spots positions should be observed and recorded. Similar treatment to this should also be given to a narrow channel, as, for example, one across a bar, where the depth is a critical one for vessels or where a lumpy or uneven bottom may be suspected; in regions of pinnacle rocks and coral heads, even this method is not sufficiently thorough, and dragging should be resorted to.*

158. Offshore lines.—In running lines from shore in accordance with a scheme which requires different spacing for different depths, the boat, after running one of the longer lines, should, in order to economize time and distance, skip the intermediate short line and return on the next long one, filling in

* A drag is difficult to improvise, and the material therefor should be specially provided. The type used successfully in the U. S. Coast and Geodetic Survey is

the shorter one next time; thus, if running lines of a given interval within 5 fathoms and of twice that interval between 5 and 10 fathoms, the method would be as shown in figure 45.

When the lines being run, either by boat or ship, reach such a distance offshore that signals are lost sight of and positions can not be fixed in the ordinary way, the course and distance made good from the last position on an outward line to the first one on the return line, as determined by the best available means, must be recorded and plotted; if the position by

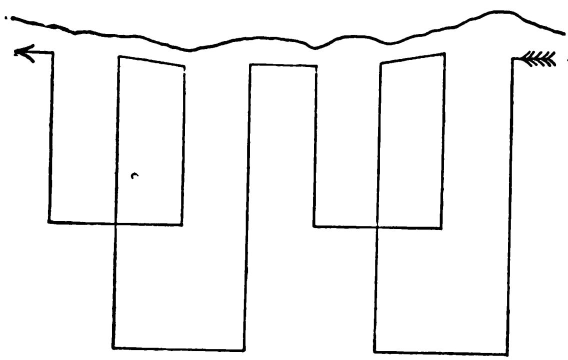


Fig. 45.

dead reckoning does not accord with that shown by angles on again picking up signals, the discrepancy must be reconciled and the proper fraction of the total error apportioned to each intermediate sounding. Launches should use the patent log in work of this character, and, since the error of their compasses is never accurately known, the true value of any compass indication should be determined by successive observed positions upon the same compass course.

159. Offshore shoals.—In developing shoals out of sight of land upon which it is not practicable to erect signals and conduct a survey according to the ordinary methods, the best available means must be adopted. One method is to anchor

made of weighted piano wire, supported at frequent intervals by buoys, the drag being suspended from the latter by wire pendants capable of adjustment in length for any desired depth and for varying stages of the tide. It is towed by two or

(or, better still, to moor) the ship upon the shoal and determine her position by astronomical observation; the lines of sounding are run by a launch, all positions thereon being referred to the ship, from which the bearing and distance are determined at frequent intervals; the bearing is observed by the ship's compass, and the distance by masthead angle of the ship from the boat—these observations being made simultaneously upon signal from the boat. If necessary, the ship may make several shifts in position in order to cover the whole area. If there is not enough water for the ship, two boats may be moored upon the shoal, their relative direction determined by compass and their distance apart by sound, and the positions of a sounding-launch established by simultaneous angles measured in each marker-boat between the other marker and the launch, in a manner similar to the location of positions from two occupied shore stations (art. 148).

160. Handling sounding boats.—In beginning a series of soundings, or in shifting to a new line from one that has been completed, the position from which the boat is to start is marked upon the boat sheet, the protractor centered over it, and the angles subtended at this point between three favorable signals are taken off; the observers then set their sextants for the right and left of these angles respectively and the boat is maneuvered until the signals subtend the proper angles, when the boat will of course be in the required position. In picking up a new line at a known distance from one that has just been left, this operation is facilitated by knowing the speed of the boat in feet per minute (which is easily obtained by measurements between successive positions) and running on time at regular sounding speed from one to another line—a method that promptly places the boat close to her required position without loss of time in trial positions.

The key to the successful running of lines is to steer on ranges whenever any natural objects are available to be

more launches using vertical bridles; an additional launch attends the depth-adjusting device on the buoys, investigates shoals discovered, keeps drag clear, and otherwise assists. The largest type of such drag sweeps a zone of half-mile width.

brought in line ahead or astern. The ranges to be steered to make good a given line may be picked up by the eye with a fair degree of accuracy; or they may be determined more closely by the method illustrated in figure 46. Let *P* be the position of the boat, as observed; *PQ,* the line to be run; and *A,* a signal plotted on the boat sheet; produce the line *PQ* toward *N,* and with the three-arm protractor, measure the angle *NPA;* set this angle on the sextant, and bring the image of *A* into view by its reflected ray; then the eye will be looking through the unsilvered part of the horizon glass along the line which it is desired to hold as a back range, and two objects,

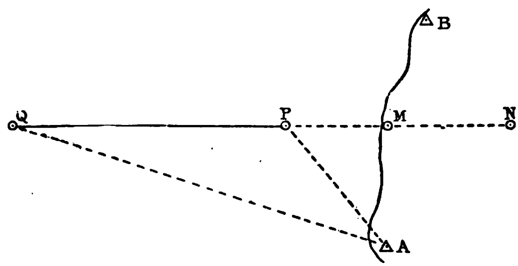


FIG. 46.

M and *N,* which mark this range, may be selected. If the boat is at *Q,* an equivalent process may be followed, but the front range will now be employed. If the signal is at *B,* to left of the line, the sextant observer looks at *B* through the unsilvered part of the glass, and the line of the range will appear as the reflected ray.

The officer in charge of a boat can vary the distance between soundings by changing either the sounding interval or the speed of the boat. The latter is limited to some extent by the depth of water; accurate soundings can be gotten in 7 to 10 fathoms at low speeds only, and in greater depths it is best to stop the engines at each cast—the machinist being instructed

to stop without further notice at the word "sound" and to go ahead when he sees that the leadsman has an up-and-down cast.

There is no danger of the lead-line fouling the propeller of a single-screw launch when the boat is going ahead on a straight course, but a boat turning with a starboard helm will almost invariably foul the starboard lead-line, or with a port helm the port lead-line; this should be especially remembered at the end of a line of soundings, where the tendency is to run for the next line immediately after the last position without waiting for the lead to be hauled in; fouling the screw not only loses time, patience, and (frequently) the lead-line, but may expose the boat to serious danger where the line of soundings ends near a lee shore. The patent log line may easily be fouled by either the screw or the sounding line, and the log should therefore be dispensed with except when necessary, which is only in offshore sounding.

161. Sounding machines of different types are used for obtaining the depth when beyond the capabilities of the hand lead to measure. They may be referred to only briefly.

162. The most elaborate of these is the deep sea sounding machine fitted to ships for ocean sounding. It is usually carried upon a platform built out over the stern, and consists of a standardized reel carrying the sounding-wire; a register for showing the number of turns out; a braking device; and a spring, with gauge, by means of which the varying tensions encountered in paying out (principally as a result of the motion of the ship) are controlled and equalized. A small steam engine is provided for reeling in the wire; to simplify that operation and reduce the strain, the weight used as a sinker is made to detach automatically upon striking bottom, so that it is not hove in after a cast. A thermometer of special form is attached to the end of the wire for recording the bottom temperature, and also a cup for bringing up a specimen of

the water adjacent to the bottom; thermometers and water-cups may be attached to the wire at other points for obtaining temperature and density of the sea water at various depths. The cylinder which carries the detachable sinker is provided with a receptacle for bringing up a specimen of the bottom soil. The ship is stopped in making a cast and maneuvered so that the wire may pay out vertically, the measure of depth being afforded solely by the amount of wire out. As the ordinary speed of paying out is about 4 minutes for 500 fathoms, to take a cast in 3000 fathoms—a moderate ocean depth—becomes a lengthy operation; the wire is reeled in only a little faster than it is paid out, but during this operation the vessel may be steaming toward the next sounding position.

163. The navigational sounding machine, with tubes or depth registers depending upon the pressure, may be used for depths not exceeding 100 fathoms, and possesses the advantage that soundings may be taken without stopping for an up-and-down cast; but though satisfactory for navigation work the pressure system lacks the certainty and exactness desirable in surveying, and vertical measures of the depth are to be preferred when time is available; these may be made with the navigational machine, the reel having been standardized for the variation of its diameter with different amounts of wire upon it.

164. Boat-sounding machines vary in type, but all combine the general features of the navigational machine in a form that permits their compact mounting upon the stern or quarter of a launch; they are further frequently fitted with a strap or belt by which the reel may be connected with a grooved collar on the engine-shaft and power thus obtained for reeling in the wire as the boat steams to the next position. As in other cases, pressure registers may be employed up to 100 fathoms if such method is deemed desirable.

CHAPTER VIII.

ASTRONOMICAL AND MAGNETIC OBSERVATIONS.

165. The objects of astronomical observation in connection with a survey are to determine the geographical co-ordinates of some definite point, and the true azimuth between two definite points of the survey; as a result of such determinations it is possible to plot all points of the survey in correct relation to the meridians and parallels of the earth.

It is assumed that the reader is fully acquainted with the principles of Nautical Astronomy, and that the discussions of this chapter may be confined to the methods employed in surveying, as more particularly distinguished from those of navigation.

166. Observation spot.—The point whose geographical position is to be determined is known as the *observation spot.* It may either be one of the triangulation stations, or may be some other point considered more favorable for observation, though in the latter case it must be in sight of at least two triangulation stations in order that its position with relation to other points of the survey may be determined. In either case, the surroundings should be such as to offer facilities for accurate observation; the neighboring foliage must not obstruct the measurement of altitudes, and the ground should not be subject to vibrations, such as those due to surf or traffic, which may disturb the artificial horizon; a locality as free as possible from insects, both by night and day, should also be chosen, for aside from questions of health and comfort, these pests may make themselves so annoying as to interfere with accurate observing. When circumstances permit, it is

best not to build the signal at the observation spot until the astronomical work is complete.

The determinations for azimuth may frequently be most conveniently made from the observation spot, though any main triangulation station may be used for this purpose.

167. Balancing errors.—The determinations made in surveying do not differ in principle from those made in navigation; but some differences in practice occur through the fact that the surveyor seeks a degree of accuracy in his results which is beyond both the capabilities and the needs of the navigator; and where the latter generally neglects as immaterial certain small errors recognized as always existent, it is the aim of the surveyor to eliminate the effect of all such with a view to obtaining the closest approach to absolute precision.

The errors referred to, and to which any measurement of the altitude of a celestial body is subject, are three in number, comprising (1) the instrumental error (which, in sextant observations, includes the error of the artificial horizon), (2) the error in the tabulated refraction, and (3) the personal error of the particular observer. It would be difficult, if not wholly impracticable, to determine the absolute amount of these errors; but we know that the instrumental error is constant for measurements made with the same instrument and on the same part of the limb; that the error in tabulated refraction is constant for the same altitude under a given condition of the atmosphere; and that the personal error is constant for the same observer, provided that a sufficient number of observations are taken to eliminate accidental variations from the mean. Hence it follows that the mean of several altitudes of a body as measured by a given observer, with a given instrument, and under given conditions of the atmosphere, will be in error in the same (unknown) amount as will the mean of a like set of measurements by the same observer, with the same instrument, and under the same atmospheric

conditions, of some other body at approximately the same altitude.

Now suppose that a body bearing south is observed, and that the effect of the errors makes the measurement x seconds too high; if the latitude is deduced by meridian altitude the resulting position will be x seconds too far south; the repetition of the observation with another body to the south would merely lead to a repetition of the error; but if one or more bodies were observed to the north at the same time and same altitude, while the altitude would be as before, x seconds too great, the deduced latitude would be x seconds too far north; hence by taking the mean of the results from the body or bodies to south with those of the body or bodies to north the error would be eliminated and the true latitude obtained. From this follows the rule that determinations of latitude should be based upon the mean of series of observations taken by the same observer, with the same instrument, and at the same time, of bodies respectively to north and to south and at approximately the same altitude; or upon the mean of several such series, bodies being always observed in pairs having like altitude but lying on opposite sides of the zenith. A similar requirement exists for the determination of hour angle by bodies to east and west. This may be called the practice of *balancing errors,* and should always be followed in surveying.

The sun must therefore be considered not available for use in latitude determinations, and star observations should be employed for this purpose. The sun may, however, be observed for longitude when at equal altitudes east and west of the meridian; for though a chance for error arises from the possibility of differing atmospheric conditions before and after noon, this disadvantage is offset by the greater accuracy of observations by daylight.

168. Astronomical transit instruments of varying form are sometimes employed in surveying, but their use is rare and,

in modern practice, becoming more so; the scope of this work will, therefore, be fulfilled by a brief description of their common features. Such an instrument consists of a telescope mounted upon a horizontal axis in such manner that the line of collimation rotates in a vertical plane truly coincident with that of the terrestrial meridian; a graduated vertical circle is fitted for the measurement of altitudes; in the focus are a number of equidistant vertical cross-wires, or lines, on each side of the middle one, and a small lamp is arranged to illuminate these for night observations; the instrument is mounted upon a concrete pillar. Latitude is obtained by measurement of the zenith distances of stars on the meridian to north and south; longitude, by their times of meridian transit, taking the mean of the observed passage on the respective cross-wires. To derive the full benefit of the accuracy of which such an instrument is capable, a chronograph should also be supplied.

169. Sextant observations, in conjunction with the artificial horizon, provide a much more convenient method of determination and one of generally satisfactory accuracy. Naturally, the high grade navigating sextant will be used for this purpose, and not one of the smaller instruments designed for hydrographic work. Every care must be taken to eliminate errors or to make uniform those which can not be eliminated.

The roof of the artificial horizon should have its ends distinguished by marks, and the same end should always be placed nearest the observer, so that any refraction arising from its glass faces may affect all altitudes alike. In observing equal altitudes of the sun, half the forenoon observations should be taken with separating limbs and half with limbs approaching (being, of course, appropriately marked in the record so that each set of afternoon observations may be taken with the limbs moving in opposite direction to the corresponding forenoon set); this eliminates any inequality in the observer's personal error for approaching and separating limbs.

The horizon should be placed so as to be as free as possible from disturbance by wind and vibration; sometimes this is accomplished by shoving the roof down into the ground, or sometimes by placing the basin of mercury on thick felt pads or several folds of a thick towel.

A sextant stand may be used in this class of work; though somewhat cumbersome, it conduces to accuracy of observation, especially with stars.

The observer and recorder should be made as comfortable as possible; the stool used by the former for a seat should be of convenient height; a screen may be erected for wind or sun; a "smudge" to keep off insects is often necessary, or a spare member of a boat's crew may be assigned to keeping a fan going for the same purpose.

For marking time a hack chronometer is preferable; it should be compared with the standard chronometer both before and after observations and as near as practicable to the time thereof.

Altitudes (except circum-meridians) are observed in series—usually of five or seven; the intervals of altitude should be equal, the sextant being set in advance and the time marked when contact is made. A test of the accuracy of the observations is afforded by noting whether the time intervals are uniform or nearly so, or whether the mean of the times corresponds closely with the time marked for the middle altitude. Very low and very high altitudes should be avoided—the former being subject to excessive and uncertain refraction, and the latter (if not off the limb) suffering from indistinct reflection of the image on the index mirror.

The observer should be assisted by an intelligent recorder whose duty is to mark time and keep the record of observations, and who should have a sufficient understanding of the methods to free the observer from all details excepting those of instrumental work.

In night observations, a bull's-eye lantern (preferably electric, with storage battery) should be provided for reading the limb of the sextant, and a deck lantern, screened from the observer, for the recorder's use.

170. For determining latitude, for which star observations should be depended upon, the observer should prepare in advance a list of stars to be used, selecting from the Nautical Almanac those which come to the meridian at the proper time and which form pairs—one north and the other south of the zenith and differing in altitude not more than 5°. As part of the preparation, the double altitude at transit is computed for each, so that the sextant may be set in advance to facilitate finding. The interval between meridian passage of any two stars should be sufficient to afford opportunity between observations for the observer to adjust his stool and the horizon roof and to find the star. The method of reduction to the meridian should be employed, a number of altitudes being measured and chronometer times marked for each star without attempting to observe the meridian altitude as such; the times and altitudes should be so chosen that the reduction in altitude does not exceed 1′, which, for moderate altitudes, allows a period of 5 minutes for observation before transit and the same amount after; the variation of altitude for one minute should be computed, instead of the tabulated value being employed.

171. For determining longitude, if star sights are used, a list of available stars is prepared in advance as for latitude, choosing those on or near the prime vertical, and forming pairs of like altitude to east and west. The sun is, however, more generally employed for this observation, equal altitudes being observed in the forenoon and afternoon; the computation is most frequently made by means of the equation of equal altitudes; but it is equally satisfactory to take the mean of results of independent series of forenoon and afternoon

observations wherein the altitudes correspond closely though not exactly—a convenient fact to remember when a passing cloud spoils the equal altitude observation.

Local time having been determined, the longitude is deduced by comparison with the time of some established meridian. This may be obtained either telegraphically or by the transportation of chronometers, the methods for both of which are explained in standard works on Navigation.

172. The true azimuth is determined by measuring, at an occupied station, the angular distance between some other station and a celestial body, and determining simultaneously the true azimuth of the body, or its angular distance from the meridian; whence, by combining the two, the true azimuth of the observed station is deduced. The measurement between the station and the body may be made either by theodolite or sextant; the true azimuth may be determined either by an altitude measured with theodolite or sextant, or by the time indicated by a chronometer whose error upon local time is known.

For measurement of the horizontal angle a theodolite gives so much more satisfactory results than the sextant that the latter would never be employed unless it were the only available instrument; in this case it is necessary to measure simultaneously the altitude of the body, the altitude of the observed station, and the angle between the two, and reduce the latter to the horizontal by the appropriate formulæ.

In using the theodolite, if the sun be observed, a colored shade glass, such as is supplied for sextants, is used to protect the eye; if night observations are made, a light is put on the station to be observed, and the cross-wires are illuminated by placing the reflecting-cap (fig. 47) upon the end of the telescope in such position as to reflect into the tube the rays of a lantern. Stars, particularly those of high declination, are well adapted to these observations, determinations by Polaris

being of the highest value; but certain inconveniences and inaccuracies are involved in night work, and observations of the sun will generally be found most satisfactory. An observation of the sun is described, and the application to other bodies will be apparent.

The theodolite is set up and adjusted, with its zero upon the station from which measurements are to be made; the upper plate is then unclamped and the telescope is pointed toward the sun. Three methods are open to the observer for determining azimuth, as follows:

FIG. 47.

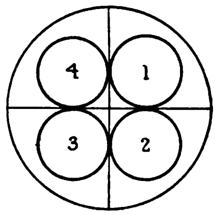


FIG. 48.

(*a*) By chronometer time;

(*b*) By altitude measured with a sextant and artificial horizon;

(*c*) By altitude measured with the vertical circle of the theodolite.

The simplest method is to make the observations for true bearing immediately after those for longitude, when the chronometer error on local time will be known from those observations and the calculation will be simple; but whether this be done or the second method be adopted (having a separate observer with artificial horizon measure altitudes simultaneously with the observation of the horizontal angle), it is only required that the vertical cross-wire of the theodolite be brought tangent to one or other of the sun's limbs, regardless of the position of the horizontal wire. Observations are thus

taken in series, "mark" being called for simultaneous reading of both observers. After a series of measurements of one limb, a like series is made for the other, the mean result eliminating the semi-diameter and being thus applicable to the sun's center; or, if only one limb is observed, it may be reduced to the center by applying a correction equal to the semi-diameter multiplied by the secant of the altitude.

If the third method is adopted and the theodolite is depended upon to measure both altitude and horizontal angle, the sun must be brought simultaneously tangent to the vertical and the horizontal cross-wires and both vertical and horizontal limbs read; and in order to effect the reduction to the center such observations must be made in groups of four, the sun being brought successively into the four quadrants surrounding the intersection of the two wires (fig. 48), the mean of the four altitudes and four azimuths being taken as the altitude and azimuth, respectively, of the center.

All observations are repeated a number of times, one-half the number with telescope reversed, for the elimination of both personal and instrumental errors. Between each series of observations the telescope should be turned back to the station from which angles are being measured, to see that the limb in this position is still upon the zero and that the plates have not been improperly moved.

The method of determining the azimuth of the sun, by either altitude or time, is a simple problem in Nautical Astronomy explained in works on Navigation. It may be remarked, however, that the approximate methods of deducing azimuth by diagrams or tables, so frequently employed for navigation work, are never to be considered sufficiently accurate for surveying.

173. Magnetic observations, when complete, comprise the determination of the variation of the compass, the dip, and

the intensity of the horizontal component of the earth's magnetic force.

174. The variation or **declination** (the former being the term uniformly employed in nautical practice) is the most important one of these elements for the mariner to know, and should be determined in connection with every region surveyed. This may be done by setting up a magnetic needle at a point free from local magnetic influence and observing the direction by compass of some object whose true bearing is known or may be determined; from a comparison of the true and compass bearings the variation is deduced, being named *east* when the true bearing is to the right, or *west* when to the left. The compass needle of a theodolite should invariably be employed for this purpose, being capable of the most exact reading.

The first step is to be assured that there is no local attraction; this is done by setting up the theodolite at the station to be occupied and observing the compass direction of one or several surrounding points upon which marks have been placed; then proceeding with the instrument to the other point or points and sighting back to the station; if the bearings to and from the respective points are truly reciprocal, the locality may be assumed to be free from local attraction; otherwise, another must be chosen.

The most convenient method of determining the variation is in conjunction with an observation for true bearing. In this case, the observations for azimuth being complete, it is merely necessary to note the magnetic bearing of the observed station and take the difference between this and the true bearing.

It has been found that the magnetic needle is affected by a daily tide, as a result of which its pointing varies from hour to hour, reaching its most eastwardly position (or elongation) about 7 a. m., and most westwardly about 1.30 p. m.; this tide

has a maximum effect in high, and a minimum effect in low magnetic latitudes. Observations for magnetic bearing should therefore be made at both eastwardly and westwardly elongation, and the mean results employed.

175. Magnetic dip and intensity are of less direct interest to the mariner, but furnish useful data for the physical study of any region, being of especial value for the construction of the charts of magnetic dip and intensity employed in compass work; they should, therefore, when practicable, be included in the determinations of a hydrographic survey. Special instruments must be provided for this purpose, a description of which need not be given here.

CHAPTER IX.

TIDAL DATA.

176. The objects of tidal observations in connection with a hydrographic survey are three-fold: (*a*) to enable the depths of water observed at various stages of tide to be reduced to their equivalents at a standard stage corresponding to the adopted plane of reference; (*b*) to deduce such information regarding the rise and fall in the region under investigation as will enable navigators to predict the stage of tide at any time and thus allow for differences between charted and existing depths; and (*c*) to deduce such information regarding tidal currents as will enable navigators to have knowledge of the probable effect thereof.

177. Definitions.—For clearer understanding of the nature of the observations, certain terms and definitions, assumed to be already known, will be briefly recalled.

Tide, while generally applicable to both the vertical and horizontal motion of the sea caused by the attraction of the moon and sun, is strictly used with reference to the vertical motion, or rise and fall only, while the horizontal motion is termed *tidal current. High* and *low tide* represent the maxima of elevation and depression; the period of no vertical change, when the tide is neither rising nor falling, is called *stand.*

Referring to tidal currents, the stream due to a rise of tide, proceeding generally from seaward toward the land, is called *flood;* the opposite stream, *ebb;* the period of transition, when there is no horizontal motion, *slack.* The direction and velocity of a tidal current are respectively designated as *set* and *drift.*

The lunitidal interval at any place is the interval between the moon's meridian passage at that place and the next succeeding high water; this varies somewhat for each day of a lunar month, though its value is approximately constant. The lunitidal interval on the days of full moon and of new moon (full and change days) is called the *vulgar* or *common establishment,* or simply the *establishment;* and since, at such times, the moon's transits (upper and lower) occur approximately at noon and midnight, this establishment corresponds closely with the local time of high water on those days; hence H. W. F. & C. (high water at full and change) has been adopted as still another designation for the same thing, and is perhaps the one most frequently employed. The mean of all the lunitidal intervals throughout a lunar month is called the *corrected establishment,* and more accurately represents mean conditions than the vulgar establishment. There is, strictly, both a high and a low water lunitidal interval, but when not otherwise specified the former is understood.

The range of tide, or *rise and fall,* is the difference between high and low water under specified conditions, as mean range or spring range. The *mean sea level* is the mean of high and low tides under corresponding conditions, and may be regarded as the level that the water would assume if tidal effects were eliminated.

Spring tides are those which occur when the attraction of moon and sun are exerted in unison, whence follow the highest high tides and the lowest low tides, or the maximum range; this condition arises at new moon and full moon, or shortly thereafter. *Neap tides* are those which occur when the attraction of moon and sun are opposed, at which time we have the lowest high tides and highest low tides, or the minimum range; this is the result of the moon being in quadrature.

The semi-diurnal type of tide is one whose effect is to produce two high and two low waters in each lunar day; the

diurnal, one which produces but one high and one low water during that time. Waves due to both of these types are usually superposed at any place, and the result is a *diurnal inequality* of tides, the forenoon and afternoon ranges being different. The effect of the diurnal wave reaches a maximum when the moon is at extreme declination, north or south, or near one of the tropics, at which time the tides are denominated *tropic* tides.

178. Tide gauges.—To measure the height of tides, a gauge is used, the construction of which is one of the first things to be accomplished upon undertaking a survey. These gauges vary in character, and the type chosen depends upon circumstances.

179. *The staff gauge* consists of a vertical staff graduated upwards in feet and tenths, which is erected in the water in a vertical position and so secured as not to be disturbed by waves or other cause; it will be found most satisfactory to attach this gauge to a vertical post or pile, or if this is not practicable, its base may be weighted and embedded securely at the bottom, the top being braced or stayed; the staff should not uncover at the base during the lowest tides, and when this requirement involves its being placed offshore and read from a distance, the reading may be facilitated by a geometrical graduation. A staff gauge is difficult to read accurately, except in quite smooth water; it should, however, be erected, even where a gauge of some other class is employed, as it affords a standard for comparison free from the possibility of mechanical defects to which others are subject.

180. *The box gauge* is used to obviate the difficulty of reading a staff gauge when the surface of the water is disturbed by waves. It consists of a vertical box of which the base is either embedded or otherwise closed, and in which, at a point as far as practicable below the surface, a few small holes are bored by which the surrounding water may be admitted, but not

with sufficient freedom to cause the surface of the water within to be materially affected by waves. Within the box is a copper float; in some cases this float carries a graduated vertical rod whose position with reference to a fixed index shows the height of water; in other cases, there is attached to the float a wire or cord which, leading over pulleys, terminates in a counterpoise that travels up and down a vertical scale and thus indicates the height. In the first attempt at construction of a box gauge it usually occurs that the apertures for admission of water are made too large, with consequent excessive motion of the float; very small holes will answer, and, indeed, if the sides of the box are not joined with special care no holes at all are needed.

181. *The automatic gauge* is by far the most satisfactory of all, and should be provided for use in connection with all careful surveys, as, without requiring to be continuously observed, it gives an uninterrupted record of the tide. A box gauge is constructed as just described and a wire from the top of the float is passed several times around a grooved sleeve, so that the latter is rotated by the rise and fall of the float in conjunction with the action of a counterpoise; working upon the shaft of this sleeve in a helicoidal groove, and thus moving forward and back with the rise and fall, is a carrier for the recording pencil, the latter bearing upon and marking a sheet of record paper which, by means of clock-work, is fed along in a direction at right angles to the travel of the pencil-carrier. The pencil is thus made to trace a curve of which one element is time and the other height of tide. The record is made upon a long strip of paper capable of containing a month's observations, which is paid out from a cylindrical roll and, after passing under the pencil, is wound into another such roll. Various devices needless to describe contribute to the completeness of the mechanism. When once in operation, the gauge requires but slight attention, it being sufficient for an observer to visit

it occasionally—preferably at least once a day—to make entries by hand upon the roll showing the time by standard clock and the height by staff gauge to afford checks upon the mechanical working; the clock-work must, of course, be wound, and the roll of record paper renewed, at proper intervals.

182. Tide observations, when not recorded by an automatic gauge, must be made at intervals which should never exceed thirty minutes, and in cases of rapid rise and fall should be less; they must be continuous and not confined to any apparent phase of the tide such as high or low water. To afford data for deduction of tidal elements, upon which future predictions of tide may be made, the observations must extend over a lunar month; or, if the gauge is read by day only, over two lunar months.

Tidal observations made with a view to the reduction of observed soundings to a standard plane of reference must be observed with a gauge erected at a place in which the tides are identical with those of the region of the soundings; the height of tide at the head of a bight may, for example, vary markedly from that at the entrance.

183. Tidal current observations should be made at regular intervals, like observations for height, but they need not be more frequent than every half hour. They should always be made at the same point or points, which should preferably be chosen in the channel frequented by vessels. The principle of the chip log may be adopted for these observations; but the chip should be replaced by a pole weighted to float vertically at the draft of a moderate-size vessel, and the line, which need be no heavier than cod-line, should carry light floats at short distances apart to keep it on the surface. The direction of the pole by compass should be noted at the end of the observation and recorded as the set.

184. The record of observations both of tide and current should be clear and complete; it should include a description

of the general locality, the character of gauge and instruments, the exact location of the observing station, and, in the case of tides, the relation of the gauge graduation to the bench mark (art. 186). The time to which the clocks are regulated should be specified, so as to enable observations to be reduced to any standard time that may be desired. Meteorological conditions should be made a part of the record, as wind and other conditions may have an important influence on tides and currents, and apparent exceptions to normal tidal effects may thus be accounted for.

185. The plane of reference is the plane to which all tidal data and soundings are referred as a standard. Different planes of reference are used; generally speaking, a uniform plane is adopted for all charts and tide tables throughout a region where the type of tide is the same, the choice depending to a large extent upon the characteristics of that type, although governed in part by the preference of the publishing authority. Four planes of reference are used: mean low water, mean low water springs, mean lower low waters, and the harmonic or Indian tide plane.

Mean low water represents a plane whose depression below mean sea-level corresponds with half the mean semi-diurnal range, while mean low water springs represents a plane whose depression is half the mean range at spring tide; mean lower low water takes into account the diurnal inequality of the tides, being used only in those regions where the inequality is marked; the harmonic or Indian tide plane is an arbitrary plane intended to approximate to that of low water at ordinary spring tides, but which represents a really lower plane in regions where there is a large diurnal inequality.

The plane of reference most widely adopted is that of mean low water at spring tide. For the information of the navigator, the plane of reference should always be stated in the legend of the chart.

186. Bench mark.—Since the permanency of a tide gauge can never be depended upon, and since the various planes of reference are in no sense absolute, but can only be determined after an extended series of observations, it becomes essential, for the permanent value of tidal investigations as well as for the guidance of future investigators, to establish a permanent *bench* to indicate an arbitrary plane to which all tidal heights may be referred. Such a bench having been selected and marked, a line of levels is run to it from the staff gauge, the height of the bench above the zero of the gauge being entered in the records of the survey. Since all tidal heights are either recorded with relation to the staff gauge or may be reduced to its graduations, it becomes a simple matter at any future time to ascertain, by leveling back from the bench, the absolute height of any theoretical plane deduced from the observations. Incidentally, the same bench establishes a plane of reference for all elevations that may be determined in the course of the survey.

The bench should be placed in a position of greatest possible permanency, as upon a sea-wall, the base of a lighthouse, the foundation of a substantial building, or the smooth face of a rocky cliff; or, failing any other appropriate position, a concrete pier should be erected for the special purpose. The mark should be placed upon a vertical surface, the symbol usually chosen to indicate it being a circle of about 3 inches diameter with the intersection of horizontal and vertical diameters defining the center or reference point; this mark should be cut into stone or concrete, or may be outlined with copper nails if on wood.

187. The reduction of data is usually a part of the work of the survey party only in so far as may be required for the smooth plotting of the results, the analysis with a view to a basis for predictions being a part of the office work in connection with the publication of results. An immediate analysis

is made, however, with the object of determining the gauge equivalent for the adopted plane of reference, which is essential as a preliminary to the reduction of soundings, for correction of sounding records and smooth plotting; the methods of treating the data for this purpose will be self-evident, as also for determining certain other elements, such as establishments, mean sea-level, ranges, etc., which may be of interest though not ordinarily required for the purposes of the survey party.

CHAPTER X.

CLASSES OF SURVEYS.

188. Surveys vary in nature according to the methods employed in their prosecution, the differences arising, on the one hand, from the difference in the character of the region under consideration, and on the other, from attendant circumstances as to available time and instruments. In general terms, surveys may be classed either as harbor surveys or reconnaissances when they relate to bodies of water of limited area, and either as coast-line or running surveys when they cover an extensive line of coast; the deep-sea survey forms still another class.

Excepting for the last-named, it is, however, impossible to draw rigid lines by which the classes may be distinguished. The theoretical requirements for all surveys are identical—that there shall be a system of accurate triangulation which, in conjunction with a measured base and astronomical determinations, shall afford a number of determined positions to which may be referred details of hydrography and topography covering every feature of the area. This, however, is an ideal condition seldom completely realized, and the indistinct lines that separate the surveys are principally dependent upon the degree of departure from this ideal necessitated by circumstances of location and the character of the observations.

189. Harbor survey is the term applied to an accurate survey of a small area, such as a harbor or bay, wherein the conditions of navigation require an accurate development of hydrography and topography, and the triangulation must therefore be sufficiently complete to afford the necessary signals for

determining position in every portion of the area. The theoretical requirements stated to exist for all surveys are in this class most nearly fulfilled.

In a harbor survey, the shallowness of water requires that soundings be made at very close intervals, in order to insure the discovery of every danger to navigation; and a complete delineation of topography is likewise essential for guidance in navigation. Fortunately it occurs that the conditions, in this case, are most favorable for accurate determinations, since the proximity of land renders possible the erection of a large number of signals of which the position may be accurately determined by a system of triangulation carried forward with stations on opposite shores and offlying islands or shoals; and by means of these signals all sounding and topography may be located.

190. A reconnaissance is the name given to a hydrographic examination of a region, usually of limited area, when the observations are not made with sufficient care or completeness to justify its designation as a survey. Such an examination may be made as the best available substitute for a survey when a closer investigation is prevented by lack of time or opportunity, or it may be made merely to afford preliminary information with a view to more thorough work at a later time. A reconnaissance may fall short of a survey in any of the numerous details of the latter, as, for example, in roughness of base measurement or triangulation, in topographical details being sketched in instead of regularly located, or in the soundings not being taken with sufficient frequency or located with sufficient accuracy to give reasonable assurance that all dangers have been discovered.

191. A coast survey is a survey of exact nature covering a large region of coast, and of which the distinguishing features, as contrasted with a harbor survey, are generally: the extension of the triangulation in a comparatively narrow line to a

very great distance, by triangles having long sides; the employment for that purpose, in conjunction with the stations on the coast, of stations either on inland elevations or offlying islands or in positions temporarily marked by the ship; the development of hydrography to a great distance offshore by lines of sounding comparatively widely spaced; and the determination of geographical positions at a station near each extremity of the region and final adjustment of triangulation according to such determinations.

192. The contrast between a system of triangulation covering an attenuated line of coast and one for an area of more or less circular form will at once be apparent; the latter seldom offers difficulty as to the location of stations; but in the former, having chosen a series of stations on the coast-line proper, the surveyor must seek the best possible location for a number of others removed from that line, in order to afford the necessary well-conditioned triangles. Islands are rare in many regions; inland elevations may require days for ascent and be cloud-capped on arrival; and carrying forward triangulation with the ship as a temporary station (art. 125), while capable of yielding very good results, is a makeshift that the conscientious surveyor hesitates to adopt in connection with the main triangulation. Choice must therefore be made according to circumstances.

193. With signals at comparatively great distances apart and the lines of sounding carried to a long distance seaward, the three-point determination for locating soundings is far less accurate in coast than in harbor work; but since, under such circumstances, depths are usually correspondingly greater, and since, where dangers exist, vessels never pass in such proximity to them as within a harbor, the nicety of determination of a harbor survey is not essential, and the possibility of a small error must be accepted. When lines carry the ship beyond the view of signals, the method of article 158 must be

adopted for plotting position. The hydrography pertaining to a coast survey is here considered to be that done by the ship beyond curves of specified depth, as 10 or 20 fathoms; the complete development of a coast also includes inshore lines of sounding run at intervals appropriate to the depth; but this part of the work is done by small boats, using a series of minor triangulation stations established for the purpose, which brings it within the category of a harbor survey.

194. The final adjustment of triangulation to accord with two observation spots near its extremities should always be adopted when the area covered is such that the probable errors of triangulation exceed the probable errors of astronomical observation. In such an estimate of errors of triangulation there should be included an allowance for error in base-line measurement, which, minute at first, will be increased in the ratio of length of base to distance of the most remote point, and thus reach a material amount when applied to the whole system. The method of making such an adjustment is explained in article 220.

195. A running survey is one of an approximate nature made to cover a coastal region, when a survey by exact methods is rendered impossible from lack of time or opportunity, or when the importance of the coast does not warrant the labor required for a precise survey. As in a reconnaissance, the methods employed may depart from the standard ones in varying degree, according to the attendant circumstances.

In the usual form of this survey, the main stations are points successively occupied by the ship in steaming along the coast, and their positions are fixed not by triangulation, but by the courses and distances run from a given starting-point, as determined by the best methods available on shipboard; the hydrography consists of the soundings taken by the ship in steaming along the coast; and the topography is made up of the positions of recognizable features on shore as given

by the intersection of direction-lines from two or more main stations, supplemented by sketches made in passing.

196. The method is shown in detail in figure 49. Suppose the ship to start at *A*, a position fixed, while the vessel is at anchor, either by astronomical observations or by bearings or angles of points within an adjacent surveyed area. Before getting under way, magnetic bearings are taken of all recognizable topographic features, such as the tangent to the wooded point, the conspicuous peak (of which the vertical angle is also measured), and the river mouth; angles may be substituted for magnetic bearings throughout this method, but the latter are preferable from many considerations. The ship steams thence to position 1, keeping careful note of the course steered and the distance run; soundings are taken at the usual intervals, using the navigational machine if the water is deep, but still keeping the hand lead constantly going as a precaution against running upon an unknown danger; in passing along, a sketch is made of the trend of shore-line, as far as it may be observed, and "bow and beam" bearings are taken on prominent objects to determine their distance. Arrived at position 1, the ship is stopped dead in the water, or the anchor may be dropped under foot if the depth is not too great, and another series of magnetic bearings is taken, including the tangent to the wooded point, the center of the conspicuous peak, the river mouth, the conspicuous tree, and both tangents to the rocky island. A new course is then laid, and the ship steams to position 2, sounding as before, and on arrival taking all possible bearings; thence to position 3, and finally to *B*, following the same process. At *B*, having reached the end of the line to be surveyed or made good such distance from *A* that it becomes necessary to obtain a new departure for dead reckoning, the ship is again anchored and her position accurately determined as at *A*.

197. In running this line, the results are plotted as the

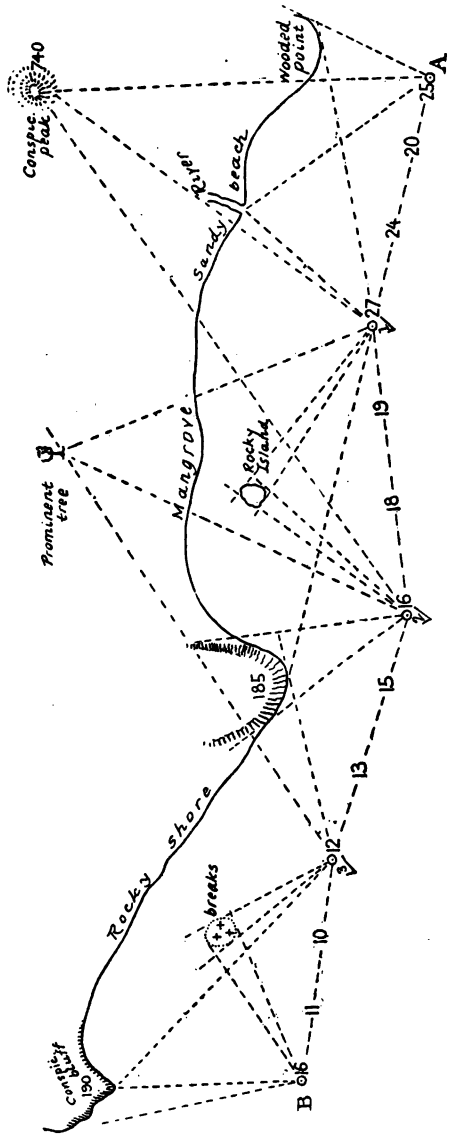

Conspic peak
740
Wooded point
A
25
20
24
Sandy
River
beach
27
Prominent tree
Mangrove
Rocky Island
19
18
16
185
15
13
Rocky shore
12
breaks
10
11
16
B
Conspic bluff
190

FIG. 49.

work proceeds, thus affording a graphic record to supplement the written one, and also facilitating the identification of objects to be observed at the successive stations; such plotting must not, however, be considered final, for the courses and distances used will probably be in error as a result of current or inaccurate logging. The position of *B*, as exactly determined, must first be compared with that given by dead reckoning, and any error in the latter thus revealed is, in the smooth plotting, distributed in proper proportion over the different parts of the run, so that new locations will be obtained for positions 1, 2, and 3. A further adjustment may be made in those positions if a single astronomical line of position has been observed at one or more of them during the wait for taking bearings. Moreover, if some clearly visible object has been well located by bearings from two or more positions, bearings from any later position may be used to locate that position from the object, instead of the reverse; for example, the conspicuous peak having been fixed by bearings from *A* and position 1, the bearing observed from position 2 may be laid down through the intersection of the first two bearings to give a direction-line for position 2. It need not be expected that, even in the smooth plotting, the agreement of results will approach that of a trigonometric survey; discrepancies will inevitably appear, and these must be reconciled as best they may; it is claimed for a running survey only that it approximately represents the conditions.

198. If practicable, a second run should be made with the ship back to the neighborhood of starting, repeating the methods of observation. The course at the first run is usually so chosen that the general trend of the coast is parallelled, at a distance sufficiently close to observe details on shore, yet far enough off to steam at regular speed without fear of dangers to navigation, having in mind that steaming at slow speed or making changes of speed interferes with accurate logging; the

return line may, if no dangers have been revealed, lie wholly inshore of the first, or it may zigzag back and forth across the first.

199. Any of the methods of a regular survey that may be practicable can, with advantage, be introduced in connection with a running survey. For example, it will be particularly helpful if a party can be sent ahead of the ship with sheeting and whitewash to build a few rough signals to assist in the identification of certain points, for on some coasts there may be a stretch of miles with no characteristic mark to catch the observer's eye. A steam launch may be employed to run an inshore line of soundings and observe the details of the shore-line, the position of this boat being fixed from time to time by angles to the ship and to prominent objects on shore; it should be remembered, however, that while the patent log gives an accurate record of distance run by a steam launch, the indications of a compass in such a boat are of small value.

200. A deep-sea survey is one covering the waters of the open ocean, in which positions are determined entirely by astronomical observation and dead reckoning; it differs radically, therefore, from the classes that have previously been considered, in all of which the positions are referred to the land.

The fixing of position in deep-sea work pertains to the subject of navigation rather than to that which we have been considering. It involves merely the most careful application of the principles by which the position of a ship is found at sea, taking especial pains to make a determination, if practicable, each time that the ship is stopped for sounding purposes; it is clearly impossible to comply strictly with this requirement, but during daylight hours, except when cloudy, the sun is always available to furnish at least one line of position, and this may occasionally be supplemented by one from the moon; and at morning and evening twilight there are always enough

bodies available to insure an accurate fix in fair weather. This rule should not, however, be extended to observation of bodies during the night hours when the horizon is not clearly defined, as results thus obtained are merely misleading. When a sounding is made at a time when no astronomical determination is practicable, the assigned position as given by dead reckoning must be amended for any current shown by subsequent observations to have prevailed since the previous fix. A good idea of the set of the surface current may sometimes be obtained by observing the trend of the sounding-wire as it pays out, the sinker descending vertically through the sub-surface water, which is generally at rest.

201. The interval at which deep-sea soundings are taken depends upon the depth of water and objects of the survey. In upwards of 1000 fathoms, for ordinary oceanography, an interval of about 20 miles will usually suffice; for bottom development with a view to laying a cable, an adopted method is to take a sounding, then steam 2 miles and take another; if there is no marked unevenness of depth, the next position may be at a distance of 10 miles; the next is a 2-mile interval, and so on, alternately 2 and 10, unless departure from uniformity is shown by the soundings, in which case extra soundings must be made to give closer development.

CHAPTER XI.

PLOTTING.

202. Projections.—Except for areas of such limited extent that the earth's curvature may be neglected, no plane chart can be made to reproduce in their actual relation to one another the positions of the various points upon the curved surface of the earth; but by adopting a conventional system of projection those positions may be represented in such manner that the actual relation may be readily deduced. Numerous systems of projection have been devised, each appropriate for a certain use; but of these only two need be considered in connection with the present subject.

203. The polyconic projection is based upon the development on a plane surface of a series of cones, each parallel of latitude being the development of the base of a cone tangent to the earth's surface in the plane of that parallel, and each meridian passing through the points of intersection of the meridians and parallels as developed. The middle meridian in this chart is a straight line, while all other meridians are slightly curved and converge toward the pole; the parallels of latitude are also curved, excepting the equator, which (the tangent cone having its apex at infinity and thus becoming a cylinder) is developed as a straight line. A great circle on this chart is represented by a line which is very nearly straight and thus makes a slightly different angle with each meridian and parallel; this fact renders it of value for plotting surveys, since on a chart covering but a small extent, as a plotting sheet, the line of sight between any two positions (a great circle) coincides practically with the line joining those positions on the chart.

204. The Mercator chart is one constructed by the development, upon a plane surface, of a cylinder tangent to the earth at the equator; before development, the meridians of longitude are projected upon the cylinder, the eye being on the polar axis of the earth; meridians thus become on the developed chart a series of equidistant parallel lines; the parallels of latitude are a series of parallel lines perpendicular to the meridians and placed (not projected) at such distance apart that a loxodromic curve, or slanting line upon the earth's surface which makes a constant angle with all meridians, shall appear on the chart as a straight line. On this chart, therefore, a straight line represents the track of a ship steering a constant course.

205. Choice of projection will therefore depend upon the uses to which the chart is to be put. The essential feature for the surveyor is that, in plotting his work, the observed direction-lines, upon which triangulation depends, shall plot, as nearly as possible, as straight lines, and that there shall be the least possible distortion of distances; and for this purpose the polyconic projection is adapted. To the navigator the feature of greatest convenience is to be able to represent as a straight line the track of his ship while on any given course; and this requirement is fulfilled by the Mercator chart. Hence surveys are usually plotted upon the polyconic projection, and when the results are complete they may be redrawn for publication upon the Mercator principle, using the geographical co-ordinates of the respective points as furnished by the first plotting; the work of redrawing may be considered as part of publication, and as such is seldom required of the survey party.

206. Small areas.—In the survey of harbors and bays of limited area the curvature of the earth has so little effect that it may be disregarded, and the results may, without material error, be plotted upon the assumption that the surface dealt with is a plane, the projection being left out of consideration.

207. The scale chosen for the plotting of the results will depend upon the character of the survey, including the closeness of sounding and other detail development; the scale must be such as to bring within the limits of a sheet of practicable size all triangulation stations used in fixing position therein. The adopted scale may be designated either in terms of inches to the mile, or in the ratio between actual and plotted distances, as $\frac{1}{10,000}$, $\frac{1}{40,000}$. The latter is generally preferable, and is especially so when the meter is used as the unit of distance in the survey, the decimal feature of the metric system lending itself to rapid reduction. A scale of $\frac{1}{5000}$ will be found a convenient one for plotting harbor surveys of the most careful sort; on this scale, the interval between lines of sounding—300 feet—occupies about .7 inch. For wider intervals of sounding and more extensive areas, the scale is reduced. It will, however, be found advantageous in every respect to plot the survey upon the largest scale that will permit the required area to be included within a sheet of convenient working size; and sometimes the area must be divided into two or more sections in order that a scale may be adopted which will be large enough for accurate plotting. Surveys should be plotted on a much larger scale than the navigational charts derived from them, as errors of plotting may thus be diminished.

208. The paper used for smooth sheets should be the best quality of drawing paper; to avoid shrinkage or extension under varying atmospheric conditions it should be backed with linen or else stretched upon a drawing-board, though even with these precautions complete permanence is not to be expected.

209. Construction of sheet.—The scale is first decided upon, and then the limits of the sheet to be constructed. Diagonal scales are constructed upon the sheet in the direction of paral-

lels and meridians; these scales expand and contract with the sheet, and to them should therefore be referred all measured distances. A straight line is drawn through the center of the sheet to represent the middle meridian of longitude, and the central point of this line is taken as the middle latitude. By means of published tables, computed from the formulæ for polyconic projections, the various points of intersection of parallels and meridians are then laid down, by rectangular coordinates from the middle meridian reduced to the scale of the sheet; through these points the respective meridians and parallels are drawn; a line called a "neat line" is then drawn around the sheet forming the outer limit of the plotted work, or the inner border line.

The first point plotted is the observation spot, which is laid down in its latitude and longitude as determined; if this coincides with one of the extremities of the base line the plotting of the other extremity of that line may be done by the true azimuth and the measured length; if the observation spot is not one of the base stations, the bearing and distance from one of those stations is computed and laid down on the sheet and the plotting then proceeds from this.

In theory, the method of plotting triangulation from an established base suggests itself; practically, however, it is not such an easy thing to accomplish satisfactorily. Graphic methods of plotting are subject to certain inaccuracies which it is so nearly impossible to eliminate that, with the utmost care, triangulation carried to a distance of a few miles on a large-scale sheet is almost certain to show irreconcilable discrepancies; for careful work, plotting by computation is therefore recommended.

210. Graphic plotting.—Before attempting, by graphic methods, to plot the position of a point from two others previously established, the three observed angles of the triangle are added together; their result, disregarding the spherical

excess which is only apparent in large triangles, should equal 180°; if it differs materially from this amount the respective angles should be increased or decreased by a proportionate share so as to be made to fulfill the condition—or, in case of a very large error, should be measured again. This adjustment made, the direction-lines to the station to be established are laid down, and their intersection marked, the position being verified by the direction-line from at least one other station. It is assumed that all three angles of every triangle have been observed; if, for any reason, one angle has been omitted, this adjustment is impossible—a disadvantage even more strongly felt in plotting by computation.

211. The errors to which graphic plotting is most subject may be enumerated as follows:

(*a*) Errors due to three-arm protractor, from defects in graduation and faulty centering;

(*b*) Errors due to inaccuracies in lines intended to join the centers of two stations;

(*c*) Errors due to stretch or shrinkage of paper.

Of the first of these, slight errors in instrumental graduation exist in a large proportion of protractors and are difficult to eliminate. Errors in centering may arise from a faulty instrument or from the failure of the draftsman to plumb the center over the station; to reduce this latter to a minimum, the center-piece with cross-lines should be chosen, and light should be thrown into it, either by a cylindrical roll of white paper placed in the plug or by a hand mirror.

Errors due to inaccuracies of lines arise from the difficulty of determining the exact center of an indicated point, by reason of the dot or prick having an appreciable width; this difficulty is increased by the fact that the straight-edge and the pencil-line for which it is a guide are not identical. The difficulty is obviated in part by drawing all lines to the longest practicable length, since a given error in linear distance has

less effect in angular distance at a remote point than at a near one; this practice should be followed even for a direction-line to a point close to an occupied station, for if it is necessary to lay off other angles from such a line it may be done more accurately from a long than a short one. The defect may also be reduced by using a very hard pencil having a chisel end rather than a sharp point, and drawing the line as close as possible to the straight-edge throughout its length, keeping the pencil always at the same inclination.

Errors due to stretch or shrinkage of paper can not be eliminated and are to be expected in plotting sheets as well as in navigating charts.

212. Plotting angles by chords, instead of by the protractor, is recommended for the main triangulation when graphic methods are used. This method depends upon the fact that, in a circle of radius R, the length of the chord AB (fig. 50) of

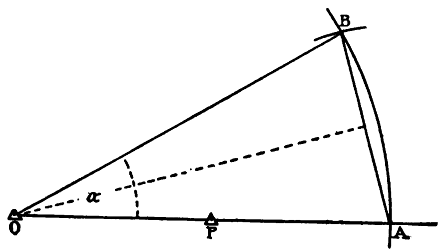


FIG. 50

any angle α subtended at the center is equal to $2R.\sin\frac{1}{2}\alpha$; if, therefore, having occupied the station O, a direction-line has been observed at an angle α to the left of the station P, the line OP is first prolonged to A, so that the radius, R, will have a sufficiently large value; (if the line OA has been drawn of good length originally, the chance of error in extending it will be avoided); the distance selected for the radius is then accurately set upon the beam compass, the point A pricked on

OA, and the arc drawn in the neighborhood in which it is known that B will fall; the length of the chord AB ($= 2R \sin \frac{1}{2}a$) is then computed and the compass set accordingly, and, with one extremity upon A, the point B is pricked where the other extremity cuts the arc AB; the required line OB may finally be drawn. If angles greater than 60° are to be laid off, it will be found more convenient and accurate to lay off 60° first, its chord being equal to the radius, and then to lay off a further angle of required size. In practice, the radius, R, may be conveniently taken at 50 inches, in which case the value in inches of $2R \sin \frac{1}{2}a$ becomes equal to the natural sine of half the angle with the decimal point shifted two places to the right; or, if the paper does not permit a radius of this length for any angle, 25 inches may be used, and the length of chord will be half as long as in the former case. The steel points should be used for both legs of the beam compass; but care must be taken not to enlarge the center-hole unduly, and not to mar the surface of the paper in sweeping the arcs—it being possible to make a mark without scratching the sheet.

213. Plotting by arcs, which may be regarded as a compromise between graphic methods and those of computation, consists in computing the length of the two sides of a triangle adjacent to the point to be determined, and sweeping these lengths as arcs from the respective points of established position, the intersection of the arcs establishing the unknown point; or both the direction and distance of the unknown point may be laid down from one station. While the method of arcs avoids the difficulties of accurate protracting, the possibility of other errors is introduced, and the results of change of form of the paper are not eliminated, so that this method is but little more satisfactory than the ones previously explained.

214. Plotting by computation is the only method that will give reliable results in triangulation of considerable extent, as, for example, in a system taking in a continuous line of coast;

and its adoption is recommended even in surveys of moderate extent, where accurate results are sought.

This method first involves computing the length of sides of the various triangles composing the main triangulation. Beginning with that triangle which includes the measured base, the known quantities in each case are (at least) one side and two angles, whence any other side may be deduced by the ordinary methods of trigonometry. The length of the various sides being thus known, the computation of co-ordinates begins—usually at the observation spot, the latitude and longitude of which point are known, together with the distance and true bearing of some main station whose co-ordinates are next to be determined. By a process usually (on account of the customary abbreviation of its terms) referred to as the "*LMZ* computation," there are deduced (*a*) the difference in latitude between the known and the unknown stations, (*b*) the difference of longitude between the same, and (*c*) the back azimuth or true bearing of the first from the second station. The analogy will at once be apparent to the familiar problem in navigation of finding, from a given course, distance, and point of departure, the latitude and longitude of a point arrived at; the difference arises only from a more exact treatment, and from dealing with the true figure of the earth instead of its projection on the Mercator chart. Seven-place logarithms are used, and the computation is facilitated by means of a series of tabulated constants deduced for each latitude with careful regard to the earth's spheroidal form. The differences of latitude and longitude thus determined, applied to the co-ordinates of the first station, give those of the second station; and from the latter station, having now the true azimuth of the first station, we may also determine by the aid of the various observed angles the azimuth of any other station; hence we have a new point from which the computation of co-ordinates

may be carried forward. Thus the process is extended to all stations of the main triangulation.

215. The advantages gained by methods of computation over graphic ones are twofold: first, a precision of determination is arrived at of which graphic methods are incapable; and, second, no error in the position of any station upon the sheet, arising either through inaccuracy in the original plotting or through subsequent change of form in the paper, will have any effect upon the plotted positions of other stations, as would be the case if the latter were deduced from it by graphic methods.

216. Adjustment of triangulation.—In order to give greater accuracy to the results of the computation, the series of angles constituting the triangulation are subjected to a process of adjustment intended to compensate for errors of observation by giving to each angle its most probable value as determined from the various conditions that it is required to fulfill. This process assumes two forms—*station adjustment* and *figure adjustment.*

217. Station adjustment is made in order to fulfill the following conditions:

(*a*) That at each station occupied, as O (fig. 51), the sum of the angles between each pair of adjacent stations, as AB, BC, ..., FA, closing the horizon, must equal 360°.

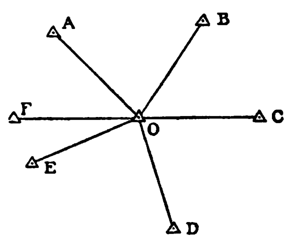


FIG. 51.

(*b*) That the sum of the angles between any two or more adjacent pairs, as AB, BC, CD, must equal the angle between the extreme stations of the group, AD.

Should the angles as observed fail to accord with these conditions, the system of station adjustment is put into effect. If no sum angles have been measured, the first condition is the

only one that can be considered, and the correction to each angle is determined by the expression:

$$\text{Correction} = \frac{360^\circ - (\text{sum of observed angles})}{(\text{number of angles observed})}.$$

If the sum angles have also been measured the most probable values of the corrections is given by an application of the method of least squares.

218. Figure adjustment is made in order to fulfill the conditions of a perfect geometrical figure. In the case of a single triangle with one known side and three measured angles the only condition is that the sum of the three angles of the triangle must equal 180°; if those angles have been equally well observed, it is most probable that they are equally in error, and the correction to each angle is:

$$\text{Correction} = \frac{180^\circ - (\text{sum of observed angles})}{3}.$$

Now, suppose that, in figure 52, we consider the triangle *ABC*. We may add together the three observed angles and if

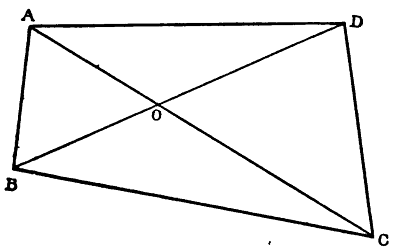


FIG. 52.

the sum does not equal 180°, we have no more reasonable assumption than that the angles are all in error in like degree, and we can only amend a given angle by adding to or subtracting from the observed value its share of the discrepancy; actually, however, the distribution of the error may be entirely different, as will be shown, by testing the angles thus adjusted

in connection with the other conditions which must be fulfilled in the quadrilateral *ABCD;* and therein lies the advantage of considering each triangle as one of the interdependent series of such figures constituting a quadrilateral.

In the case of a quadrilateral the geometrical conditions upon which the process of adjustment is based are the following:

(*a*) The sum of all the angles of any triangle must equal 180.° (*plus* the spherical excess) and the opposite angles at the intersections of the diagonals (*AOB-DOC, AOD-BOC*) must be equal.

(*b*) The computed length of any side when obtained from any other side through two independent sets of triangles shall be the same in both cases; thus, the length of side *DC,* computed from the side *AB,* must be the same if calculated through the triangles *ABD, ADC,* as if derived from the triangles *ABC, BCD.*

The adjustment required to fulfill the first condition is known as the *angle equation adjustment,* and that required to fulfill the second condition as the *side equation adjustment.* Like the complete station adjustment, the actual processes depend upon the method of least squares.

219. The detailed methods of plotting by computation, including the processes of adjustment, are explained in works that treat the subject of surveying in its entirety; such works will usually be found in the libraries of naval vessels.* Even when, through lack of time or other causes, the computed results are not submitted with the report of survey, provision should be made for computation in the office of publication, and to this end the angles of the main triangulation at any station should be observed in such combinations as to permit

* "Theory and Practice of Surveying," by J. B. Johnson; "Topographic Surveying," by H. M. Wilson; "Treatise on the Adjustment of Observations," by T. W. Wright.

of station adjustment, and the position of triangulation stations should be chosen with a special view to the formation of quadrilaterals.

220. Adjustment to check observation spot.—Where a second determination of geographical position is made and is adopted in preference to a determination of the same position by triangulation, as in a coast survey (art. 194), the method of adjustment is to apportion the discrepancy in latitude at the respective stations according to their differences of longitude, and the discrepancy in longitude according to the differences of latitude at the stations.

Thus, let L and L' be respectively the latitudes of the first and the second observation spots, as given by the astronomical determinations, and λ and λ', the corresponding longitudes; also let l and D be the differences, in latitude and longitude respectively, between the positions of the second observation spot as given by observation and by triangulation, giving to these quantities the algebraic signs representing the direction of application to the position by triangulation. Then, at any intermediate station of the triangulation whose latitude is L'' and longitude is λ'', the correction to be applied to the position as given by triangulation in order to effect adjustment, giving heed to the signs, will be:

$$\text{Correction in latitude} = \frac{\lambda'' - \lambda}{\lambda' - \lambda} \times l;$$

$$\text{Correction in longitude} = \frac{L'' - L}{L' - L} \times D.$$

221. Symbols.—The position of a station having been plotted upon the sheet, it is marked by a pricker—an instrument consisting of a needle carried in a handle, frequently a part of the right-line pen; the hole should be made as small as possible to be seen, and the pricking and similar fine drafting work should be done under a reading-glass for greater accuracy. The position of a main triangulation station is further

CONVENTIONAL SIGNS AND SYMBOLS

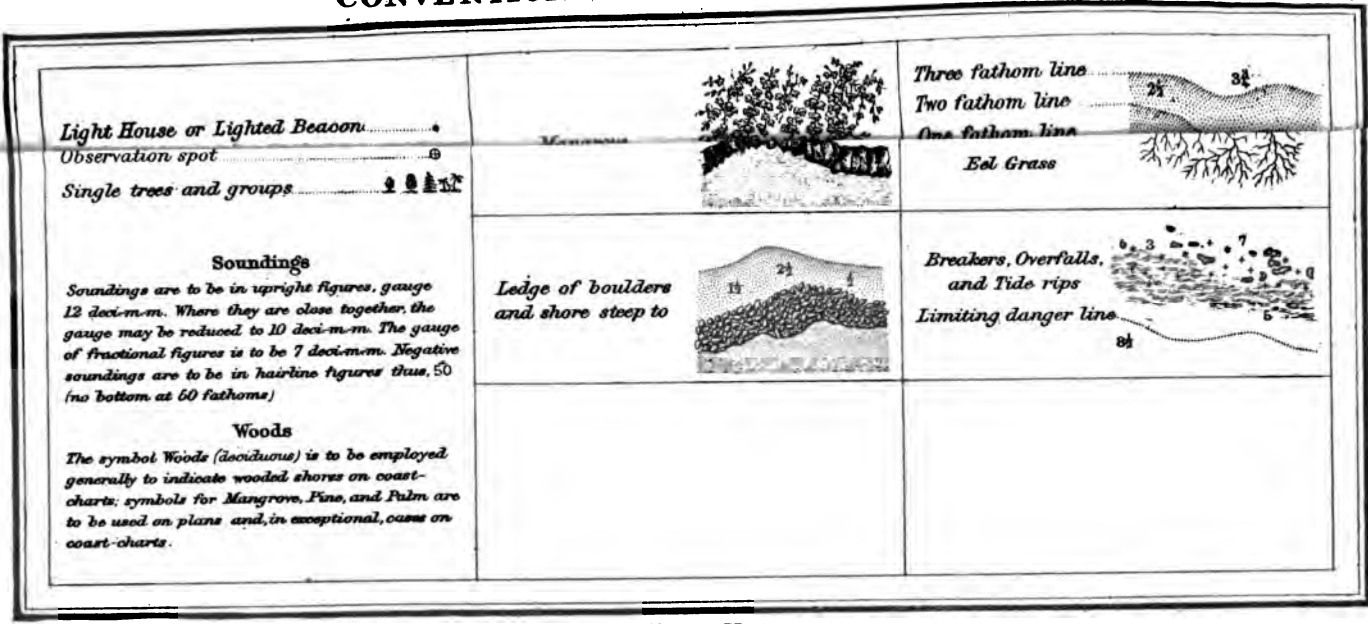


PLATE II.

marked by a small red circle inscribed in an equilateral triangle, and of a secondary station by the circle only; and these symbols are used to indicate stations of the respective classes in survey records generally. On the sheet the names of main stations are lettered in capitals, and of secondary stations in small letters.

The principal symbols used on charts issued by the United States Hydrographic Office are shown on plate II; these symbols accord closely with those employed on the nautical charts of all nations. On American charts the rule prevails that lettering pertaining to features on land shall be in upright type, while that pertaining to features of the water area shall be italic.

222. Soundings.—It should be the endeavor to plot upon the smooth sheet as many of the observed soundings as the scale will allow, in order to show the depth at the largest possible number of points and thus indicate any irregularities in the bottom; when, however, the chart is published for navigational work, many of the soundings are omitted for the sake of convenience and clearness, and only a sufficient number printed to show the characteristics of any region. The quality of the bottom is indicated with such frequency as may be necessary, employing the standard abbreviations therefor, which are as follows:

Clay	C	Stone	St	Soft	sft
Coral	Co	Weed	Wd	Black	bk
Gravel	G	Rocky	rky	Red	rd
Mud	M	Fine	fne	Yellow	yl
Sand	S	Coarse	crs	Gray	gy
Shells	Sh	Stiff	stf		

Soundings should be given either in fathoms or feet, it being customary to use the former for all excepting harbor surveys. Contour curves of equal depth are drawn at certain intervals selected in accordance with the character of the region.

223. The positions of soundings are either transferred to the smooth sheet directly from the boat sheet (art. 155), or may be replotted thereon by the three-arm protractor. The positions having been lightly pricked and numbered in pencil, and a line drawn joining successive positions, the interval between each two positions is divided to correspond to the number of intervening soundings. This may be most expeditiously done by means of a series of equidistant parallel lines drawn upon a piece of tracing-linen, or otherwise arranged so as to be superposed upon the smooth sheet. In figure 53, *T T′*

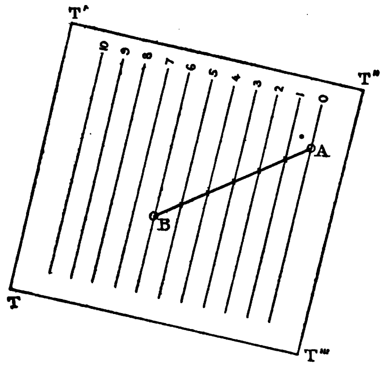
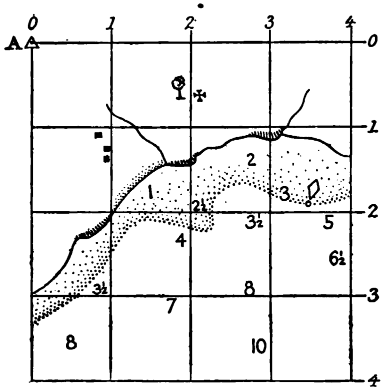


FIG. 53.

T″ T‴ represents a sheet of tracing-linen upon which are drawn the equidistant parallel lines numbered as shown, beginning with zero; the perpendicular distance between these lines should be not greater than the shortest interval between soundings. Suppose that it be required to divide the distance *AB* on the smooth sheet into a number of equal parts—say six. Place the linen upon the sheet, and let the zero line pass through *A*; then turn the linen about *A* as a pivot until the line marked "6" passes through *B*; prick lightly through upon the sheet the points at which the respective parallel lines intersect *AB*, and these will represent the intervals required.

224. Topography is plotted upon the smooth sheet either directly from observations, or by being plotted on an auxiliary sheet (of drawing-paper or tracing-linen) on an identical scale and thence transferred to the smooth sheet; the former method is generally to be preferred when the positions are established by some simple means, as that of triangulation, which does not unduly mar the sheet; the latter should be adopted when the method involves numerous lines and pricks that would deface the smooth sheet; to avoid effects of stretch and shrinkage of paper, the transfer should be made promptly after the original plotting.



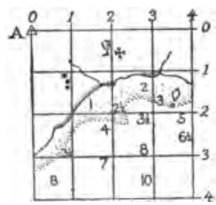


FIG. 54.

225. The transfer to a chart of different scale of topographic and hydrographic features may be made, in the absence of special instruments for the purpose, and sometimes more satisfactorily than with such instruments, by the method illustrated in figure 54. Suppose it is desired to reproduce the larger chart on a scale only half as large; beginning at some established point, *A*, on that sheet, draw two series of equidistant parallel lines perpendicular to one another, spaced as may be considered most convenient; through the correspond-

ing point, *A*, of the smaller sheet, draw like series of lines, making the spacing one-half that previously employed; the two sheets will now be covered with a number of squares of which corresponding ones represent corresponding areas; number or letter the lines in series so that they may be readily identified; then any feature of the larger chart can be represented in its proper position upon the smaller one by plotting it in its correct relation to the co-ordinate lines; thus shoreline, soundings, topographical symbols, and the like, are quickly transferred with sufficient accuracy by the eye, or, where greater exactness is required, by the aid of ordinary dividers. The method is of course applicable to enlargements as well as reductions, though in this more care is necessary. The co-ordinate lines may either be drawn upon the sheets direct, using a pencil so that they may be erased after the transfer is complete, or they may be ruled upon a piece of tracing-linen overlaid in proper position.

APPENDIX I.

Distance in Feet Corresponding to the Angle Subtended by a Ten-foot Pole.

Angle.	Dist.	Angle.	Dist.	Angle.	Dist.	Angle.	Dist.
° ′	ft.	° ′	ft.	° ′	ft.	° ′	ft.
12 00	48	3 00	191	1 42	337	1 00	573
11 00	52	2 55	196	1 40	344	0 59	583
10 00	57	2 50	202	1 38	351	0 58	593
9 00	64	2 45	208	1 36	358	0 57	603
8 30	67	2 40	215	1 34	366	0 56	614
8 00	72	2 35	222	1 32	374	0 55	625
7 30	76	2 30	229	1 30	382	0 54	637
7 00	82	2 25	237	1 28	391	0 53	649
6 30	88	2 20	245	1 26	400	0 52	661
6 00	95	2 15	255	1 24	409	0 51	674
5 30	104	2 10	264	1 22	419	0 50	688
5 00	115	2 05	275	1 20	430	0 49	702
4 45	120	2 00	286	1 18	441	0 48	716
4 30	127	1 58	291	1 16	452	0 47	731
4 15	135	1 56	296	1 14	464	0 46	747
4 00	143	1 54	301	1 12	477	0 45	764
3 50	149	1 52	307	1 10	491	0 44	781
3 40	156	1 50	312	1 08	505	0 43	799
3 30	163	1 48	318	1 06	521	0 42	819
3 20	172	1 46	324	1 04	537	0 41	838
3 10	181	1 44	330	1 02	554	0 40	859

APPENDIX II.

Table of Dip for Computation of Heights.

Distance (naut. miles).	Dip (feet).	Distance (naut. miles).	Dip (feet).	Distance (naut. miles).	Dip (feet).
0.5	0.2	10.5	97	20.5	370
1.0	0.9	11.0	107	21.0	388
1.5	2.0	11.5	117	21.5	407
2.0	3.5	12.0	127	22.0	427
2.5	5.5	12.5	138	22.5	446
3.0	7.9	13.0	149	23.0	466
3.5	10.8	13.5	161	23.5	486
4.0	14.1	14.0	173	24.0	507
4.5	17.8	14.5	185	24.5	529
5.0	22.0	15.0	198	25.0	551
5.5	26.6	15.5	212	25.5	573
6.0	31.7	16.0	226	26.0	596
6.5	37.2	16.5	240	26.5	619
7.0	43.1	17.0	255	27.0	643
7.5	49.6	17.5	270	27.5	667
8.0	56.4	18.0	286	28.0	691
8.5	63.7	18.5	302	28.5	716
9.0	71	19.0	318	29.0	741
9.5	79	19.5	335	29.5	767
10.0	88	20.0	353	30.0	793

APPENDIX III.

LIST OF ARTICLES REQUIRED BY A PARTY FOR CONSTRUCTION OF A TRIPOD SIGNAL.

Scantlings (3 large for legs and 1 small for flagpole).
Bolts with nuts and washers (1 set for use and 1 spare).
Boards for sides, anchors, and cages.
Sheeting.
Lime in bucket, with extra bucket in which to mix.
Whitewash brushes (2).
Nails for boards and tacks for sheeting.
Cordage for guys (if to be used).
Tripping-line for heel of flagpole.
Plumb-bobs (two, one having an extra long cord).
Bottle with name of station enclosed for sub-surface mark, or cement for permanent surface mark, or both.
Tools—comprising axe, pick, shovel, machetes, hand-axe, hatchet, hammer, saw, auger, and bit, or so many thereof as may be required.
Binoculars.
Wigwag flag.
Luncheons and drinking-water.
Theodolite or transit with angle book, pencils, etc. (if station is to be occupied on same visit).

APPENDIX IV.

LIST OF ARTICLES REQUIRED FOR TRIANGULATION PARTY.

Theodolite or transit.
Sextant (for angles that it may be possible to observe only from aloft).
Binoculars.
Angle book, with pencil, knife, and eraser.
Shade umbrella.
Hand-axe, machete, and climbers (for clearing instrument position and lines of sight).
Wigwag flag.
Luncheons and drinking water.
Dark spectacles for observer and recorder (for tropical work).

APPENDIX V.

LIST OF ARTICLES REQUIRED BY BOAT SOUNDING PARTY.

(Launch assumed to be equipped with such articles as fuel, water, oars, leadsmen's platforms, anchor and cable, boat box, medical emergency box, and wigwag flags).

Boat sheet mounted on drawing board.

Three-arm protractor.

Parallel ruler and dividers.

Sextants (1 for each observer).

Clock or watch, regulated to ship's time.

Ship's compass, secured.

Binoculars (1 for each observer).

Lead lines (2 for use and 1 spare).

Boat sounding machine, with leads and wire complete (if to be used).

Patent log (if required).

Small buoy, with anchor and line, for marking shoals.

Sounding book, with pencil, knife, and eraser.

Lunches and drinking water.

Dark spectacles for observers, helmsman, and leadsmen (for tropical work).

INDEX.